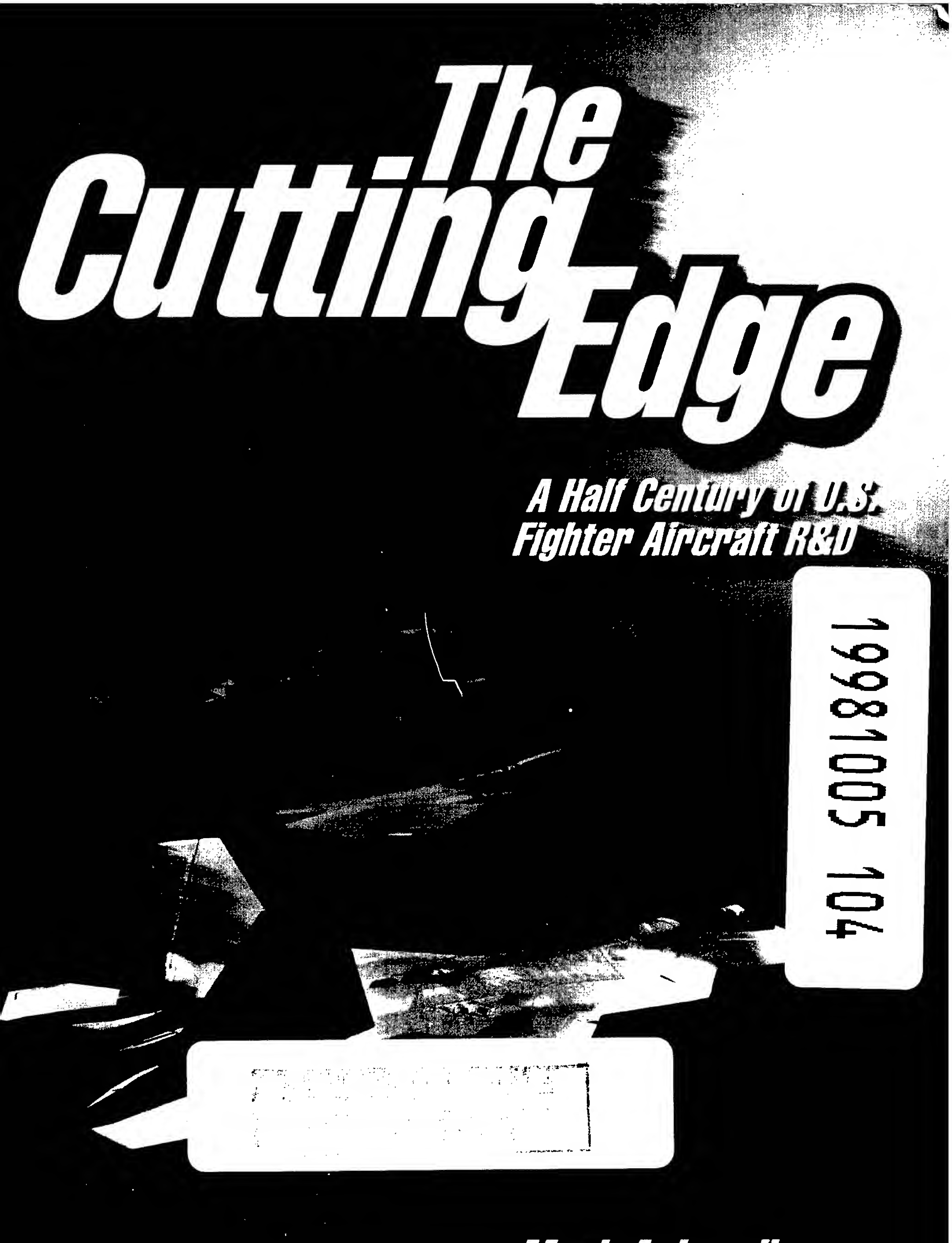

The Cutting Edge

A Half Century of U.S. Fighter Aircraft R&D

Mark A. Lorell
Hugh P. Levaux

Project AIR FORCE

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PREFACE

This book assesses the major trends in the history of jet-fighter design and development in the United States since World War II in order to evaluate the role of prior fighter and bomber and related research and development (R&D) experience among prime contractors in promoting successful R&D programs. The research is based primarily on open published sources. The goal is to assist the U.S. Air Force in developing policies that will preserve the capabilities of the combat aircraft industrial base in an environment of declining budgets and few new program starts.

This book builds on earlier RAND research reported in *Maintaining Future Military Aircraft Design Capability.*[1] This research is part of a larger study effort intended to provide a conceptual framework for analyzing the future of Air Force industrial-base R&D activities. It complements an earlier parallel study on the importance of experience for bomber R&D: Mark Lorell, with Alison Sanders and Hugh Levaux, *Bomber R&D Since 1945: The Role of Experience,* MR-670-AF, December 1995.

Decisionmakers and budget and program planners who are concerned about how the declining size and experience base of the U.S. military aerospace industry may affect the industry's ability to support future programs based on military requirements will find this work helpful. This research should be of interest not only to our sponsor, the U.S. Air Force but also to other government agencies that are responsible for supporting military aerospace R&D as well (Navy, Army, the Defense Advanced Research Projects Agency, and the National Aeronautics and Space Administration).

This research was sponsored by the Office of the Assistant Secretary of the Air Force (Acquisition) and the Aeronautical Systems Command at Wright Patterson Air Force Base. It was performed within the Resource Management and System Acquisition Program of Project AIR FORCE, RAND.

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[1]Drezner et al. (1992).

PROJECT AIR FORCE

Project AIR FORCE, a division of RAND, is the Air Force federally funded research and development center (FFRDC) for studies and analyses. It provides the Air Force with independent analyses of policy alternatives affecting the development, employment, combat readiness, and support of current and future aerospace forces. Research is being performed in three programs: Strategy and Doctrine, Force Modernization and Employment, and Resource Management and System Acquisition.

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SUMMARY

INTRODUCTION AND OVERVIEW

Past and ongoing RAND research indicates that experience—i.e., the steady buildup and maintenance of expertise over time through constant "learning by doing"—is critical in the cost-effective design and development of successful military aircraft. This proposition is, however, still subject to some debate; given its critical importance for choosing correct policies, more evidence on it would be very valuable. For example, achieving a better understanding of the role of experience in military aircraft R&D is crucial for determining how to maintain a viable U.S. industrial base for the future in an era of declining R&D budgets, few new program starts, and industry contraction. This book, and a companion document that concentrates on bomber R&D,[2] analyze the role of experience in combat aircraft R&D through a systematic review of the historical record from the early 1940s to the present of the major prime contractors in developing new fighter and bomber aircraft, using openly available published sources. This research complements and supports other theoretical and historical research reported elsewhere.

The analysis uses the distinctions regarding aerospace contractor capabilities developed by Hall and Johnson,[3] who argue that three types of capabilities reside in the aerospace industry: *general, system-specific, and firm-specific.* General capabilities are possessed by all active contractors and are necessary for each to function and survive in the industry. In the context used here, general capabilities include the ability to design and manufacture airplanes, but not necessarily fighter airplanes. System-specific capabilities are only possessed by certain firms that specialize in specific types of aerospace systems. We find that system-specific capabilities are of great importance for successful

[2]Lorell (1995).

[3]See Hall and Johnson (1968).

fighter and bomber R&D and are directly related to experience in developing these types of aircraft. Only one or a handful of firms possess firm-specific capabilities; they arise from unique activities or a combination of all activities of that firm and often pertain to a specific technology area, such as stealth. Firm-specific capabilities are also largely a product of experience. We find that firm-specific capabilities have often been extremely important during the history of fighter and bomber R&D, particularly during periods of great technological change, and have not always been the result of experience in fighter or bomber development. We conclude, in summary, that both system- and firm-specific capabilities are important for enduring contractor success.

For analytical purposes, this book divides the five decades since World War II into three broad periods of fighter development. Each period is characterized by different clusters of dominant technology challenges, military requirements, procurement environments, and attitudes toward the role and importance of fighter aircraft.

The first period extends from the mid-1940s to the end of the 1950s. It is characterized by the central role of nuclear weapons and the doctrine of massive retaliation. More importantly, this period saw dramatic technological change and innovation—as fighters and bombers shifted from piston to turbojet engines—and the government funded large numbers of procurement and technology-demonstration programs.

The second period stretches from the beginning of the 1960s into the mid-1970s. It is characterized by a dramatic decrease in the number of new program starts, as Secretary McNamara and others attempted to reform the acquisition process by promoting multirole and multiservice fighters. A combination of technology trends, rapidly rising R&D costs, dramatic changes in procurement approaches by the government, and lessons learned in air combat in Vietnam and other conflicts led to a period of great uncertainty and debate over fighter doctrine and requirements. In the end, both the Air Force and the Navy rejected the 1950s trend toward ever higher, faster, heavier multirole fighters, returning to an emphasis on the air superiority mission with agile, highly maneuverable fighters.[4]

Finally, the last period, which spans the mid-1970s to the present, is dominated by the stealth revolution. As in the first period, this period is characterized by dramatic advances in technology that enable the achievement of performance goals and characteristics that had not previously been attainable. It also is

[4]However, the F-16, which was developed in the early 1970s, was intended to be a lightweight air-to-air fighter, but as a result of allied requirements, it was eventually given an air-to-ground capability as well. Thus, the Air Force and Navy were not always able to achieve their desired emphasis on air superiority. See Chapter Five.

seeing reshuffling of the existing leadership ranks in both fighter and bomber R&D among aerospace contractors.

RESEARCH APPROACH: HISTORICAL AND DATABASE ANALYSIS

This book reviews and assesses the overall history of the major prime contractors in developing jet fighters since World War II. In addition, the role of experience is examined using a database recently developed by RAND. The database helps us track historical trends in aerospace R&D experience by contractor, aircraft type, and type of R&D.

Described in detail in Appendix A, the database contains descriptive, historical, and numerical information on 223 major fixed-wing military and commercial aircraft R&D programs undertaken by U.S. aerospace contractors between 1945 and 1995, as counted in the eight categories shown in Table S.1.[5] In addition, 341 entries of distinct models and versions of these military aircraft are included in the database.[6] The database in most cases also distinguishes four principal phases or types of R&D: (1) design, (2) technology demonstrator or prototype, (3) full-scale development, and (4) modifications and upgrades. X-plane R&D programs are treated as a separate, fifth category of R&D.[7] Other distinctions are made, such as supersonic versus subsonic, and stealth versus nonstealth. Experience is measured in terms of the number of programs and their size.[8]

This is an extensive database. Nearly all jet fighters, fighter-attack aircraft, and bombers developed and flown by U.S. industry since 1945—as well as all fighter

---

[5]The database includes fighter-attack and attack aircraft whose official designation begins with an "A," such as the A-4, A-7, or A-10, in the category of fighter aircraft. From the technical perspective, these aircraft are generally much closer to fighters than to heavy bombers. However, the report focuses mostly on fighter aircraft that bear the official "F" designation, and discusses attack aircraft only peripherally.

[6]A program is defined as an R&D effort for a specific aircraft, such as the F-84, F-4, B-1, C-141, Boeing 707, and X-31. Aircraft versions refer to major new models, modifications, or upgrades of the same basic aircraft. Thus, separate data entries exist for the F-4C and F-4E, for example. Radical modifications or upgrades, such as the F-84F, the F-86D, or the B-1B, are treated as new aircraft programs.

[7]This category includes the X-1 through the X-31 relevant to this study. X-planes are intended for proof testing of one technology or set of technologies and are seldom meant to be developed into operational aircraft. XF and XB programs are treated as technology demonstrators or prototypes because such programs are usually meant to have the potential of entering into full-scale development and becoming operational aircraft. All X-planes are assigned to one of the eight aircraft types shown in Table S.1.

[8]The number of work days between the two milestones that define a specific phase of a program is used as a surrogate for program size. Although this approach has many shortcomings, it remains the best feasible approach, since insufficient data have been collected and organized at this time to use cost or expenditures as a measure of size.

Table S.1

Database Overview

Aircraft Categories	Programs	Aircraft Versions
Fighter	106	171
Bomber	26	48
Reconnaissance	10	20
Trainer	6	11
Military Transport	18	25
Unmanned Vehicle	23	24
Miscellaneous	16	23
Commercial Transport	18	19
Total	223	341

and bomberlike prototypes, technology demonstrators, and X-planes—are included in the database. In addition, most major modifications, upgrades, and significant new models of existing fighters and bombers are included.[9]

This book uses analysis of this database, combined with a broad analytical survey of the overall history of U.S. fighter R&D since 1945, to provide insights into the role of experience in fighter development. Because of resource constraints and lack of availability of first-hand sources, the database largely relies on published materials, rather than primary documents or personal interviews, for its information.

CONCLUSIONS

From examination of the history of fighter R&D in the United States since the mid-1940s, we conclude that

- Experience matters. Prime contractors tend to specialize and thus to develop system-specific expertise. For most of the period under consideration, successful contractors built on a clear and uninterrupted progression of related R&D programs, as well as design and technology projects. A

[9]Although we believe the database is one of the most extensive in existence, a variety of data limitations and other constraining factors resulted in numerous gaps. For example, a few "letter" models of specific types of fighters are not included, because insufficient data were available in published sources or for other reasons. One well-known "letter" model—the F-4G—is not included because this model was entirely derived from rebuilding existing airframes of other variants. The database has no separate entries for different "block" versions of fighter aircraft, even though some block versions vary significantly from each other, such as the F-16C/D Block 40 compared to the F-16C/D Block 50. Data on military aircraft other than fighters, attack aircraft, and bombers are considerably less complete. Many but not all large commercial transports are included.

strong experience base in specific types of military aircraft R&D or in specific technology areas appears to have been extremely important. Special measures for maintaining the experience base may be critical for a viable aerospace industry capable of meeting future military requirements.

- The historical evidence indicates little correlation between expertise in commercial transport development and successful fighter R&D. However, there appears to be a strong link between expertise in fighter development and bomber R&D. Therefore, commercial aircraft development programs are unlikely to provide the necessary experience base for future military aircraft R&D programs.
- During periods of normal technological evolution, high intraindustry entry barriers inhibit prime contractors from changing their areas of specialization, further suggesting the importance of system-specific expertise. During periods of radical technological change, however, entry and success in new areas of specialization take place, causing major changes in R&D leadership. Much of the dynamism in military aircraft technology in the past appears to have been promoted by intense competition among many firms, each driven to risk dramatic new technological approaches to increase its market share. This then implies that a dynamic military aircraft industrial base may require more than two or three prime contractors or specialized divisions.
- Over the past 50 years, dedicated military R&D conducted or directly funded by the U.S. government has been **critical** in the development of new higher-performance fighters and bombers. Major new breakthroughs in combat aircraft technology, design approaches, and concepts have come far more often from government labs or government-sponsored military R&D carried out by military contractors than from the commercial sector. As a result, the contribution of commercial technology to future military aircraft design and development may be limited, at least on the overall system level. However, the contribution of commercial technology and manufacturing processes could be significant, especially on the parts, components, and subsystem levels and in the area of electronics.

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ABBREVIATIONS

ATA	Advanced Tactical Aircraft
ATB	Advanced Technology Bomber
ATF	Advanced Tactical Fighter
CSIRS	Covert Survivable In-Weather Reconnaissance/Strike
DARPA	Defense Advanced Research Projects Agency
dem/val	Demonstration and validation
DoD	Department of Defense
FBW	Fly-by-wire
FSD	Full-scale development
GD	General Dynamics
HiMAT	Highly Maneuverable Technology
IR	Infrared
JSF	Joint Strike Fighter
LTV	Ling-Temco-Vought
LWF	Lightweight fighter
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
OSD	Office of the Secretary of Defense
R&D	Research and development
RAM	Radar-absorbing material
RCS	Radar cross section

RFP	Request for proposal
RFP	Request for proposals
STOL	Short takeoff and landing
TFX	Tactical Fighter Experimental
THAP	Tactical High-Altitude Penetrator
USAAC	U.S. Army Air Corps
USAAF	U.S. Army Air Force
USAF	U.S. Air Force
VFAX	Navy Fighter Attack Aircraft Experimental
V/STOL	Vertical/short takeoff and landing
VTOL	Vertical takeoff and landing
XST	Experimental Survivable Testbed

Chapter One

INTRODUCTION

BACKGROUND AND OVERVIEW

For the first three decades of the history of military aviation—from the early years of World War I until the middle of World War II—U.S. fighter technology generally lagged well behind the leading-edge developments in Germany, the United Kingdom, and other foreign countries. However, the shock of deadly confrontations with superior Japanese fighters early in World War II and with advanced German jet fighters at the end of the war helped change the attitude of the U.S. government toward advanced military aircraft research and development (R&D). After the war, these factors, combined with the growing tensions of the new Cold War with the Soviet Union, led America to build up the most capable and advanced fighter R&D industrial base in the world. Throughout the more than four decades of tense standoff with the Soviet Union following World War II, the United States supported many military aerospace R&D projects on a scale and at an overall level of funding that far surpassed that of any other Western country.

The dramatic decline in the overall size and employment in the U.S. military aerospace sector that has taken place since the end of the Cold War raises serious questions about the long-term ability of the industry to continue providing the U.S. Air Force and Navy with the world's most capable aerospace weapon systems in a timely and cost-effective manner. With fewer and fewer new program starts, defense planners may need to implement special measures to maintain the industry's expertise and experience levels at satisfactory levels to meet future military R&D requirements effectively. Such measures could prove to be expensive and difficult to implement, and therefore should be carefully crafted to maximize their effectiveness. The formulation of effective remedial measures—if indeed they are necessary—requires an in-depth understanding of all the factors that contribute to superior design and development capabilities. In particular, the roles such factors as uninterrupted experience in hardware design and development, specialization in specific system types or technologies, and competition among different design and development teams play

in maintaining key skills and capabilities need to be better understood by policymakers and analysts.

Past and present research on this subject suggests that experience—i.e., the steady buildup and maintenance of expertise through constant "learning by doing"—plays a critical role in the cost-effective design and development of successful military aircraft. Drezner et al. argue that "experience in designing, building, and testing aircraft is a crucial asset for design capability."[1] They further maintain that

> to be really good at designing combat aircraft, members of a design team must have had the experience of designing several such aircraft that actually entered the flight-test stage. Paper designs and laboratory development are important, but they are not a substitute for putting aircraft through an actual flight-test program.[2]

These propositions are based on extensive—although often anecdotal—evidence and seem intuitively reasonable. They are supported almost universally by the strongly held opinions of aerospace industry managers and engineers. However, they are still subject to debate, and given the importance of the policy issues on which they bear, more evidence on the importance of experience in the design and development of military aircraft would be very valuable.

This book analyzes the role of experience in combat aircraft R&D through a systematic review of the historical record of the major prime contractors in developing jet-fighter aircraft, derived primarily from open published sources. A companion report analyzes bomber R&D.[3] The objective is to assess to what extent—and how—prime contractors built and maintained a competitive design and development capability for fighter aircraft over the past decades through continuous experience and learning by doing. The goals of the research are to improve understanding of both the relative importance of experience in maintaining design and development capability and the processes through which firms acquire experience. The types of questions the research addresses include

- Did successful[4] contractors build on a clear progression of closely related R&D programs or design and technology projects? What were the links among these projects?

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[1]Drezner et al. (1992), p. 14.

[2]Drezner et al. (1992), p. 16.

[3]Lorell (1995).

[4]The appropriate definition of "successful" is discussed in detail below.

- Did contractors tend to specialize in specific aircraft types—such as fighters—or in specific clusters of technologies—such as those directly related to fighters?
- Have any successful contractors experienced unusually large time gaps between major fighter R&D programs, then successfully reentered the field? How did such contractors maintain their capabilities during these gaps?
- Are there any examples of successful new entrants into the fighter development business from other aerospace specializations or other industries since World War II? Are there any examples of a contractor exiting the fighter R&D business entirely for a substantial time and then successfully reentering?
- Have previously successful contractors withdrawn from the market either voluntarily or involuntarily? Why?
- What changes in any of the phenomena listed above can be detected over time? What caused these changes?

The research conducted to help answer such questions regarding fighter R&D builds on the research and the findings described in an earlier companion report, *U.S. Bomber R&D Since 1945: The Role of Experience.*[5] The earlier document reviews the historical record of major prime contractors in developing new bomber aircraft and assesses the significance of R&D experience for building and maintaining a competitive design and development capability for such aircraft. Focusing on the development of bombers from the early 1940s to the mid-1990s, it concludes that historical expertise in bomber R&D was a critical factor behind the success of the U.S. prime contractors that made the most significant contributions during the period following World War II. Both this book and *U.S. Bomber R&D Since 1945* complement and support other theoretical and historical research reported elsewhere.

This book conducts a similar review of the overall U.S. industry record in designing and developing jet-fighter aircraft over the 50 years spanning the early 1940s to the mid-1990s. This period encompasses the introduction and rapid rise to near-total dominance of jet-powered military aircraft and was dominated largely by the Cold War. The primary focus of this research is on the development of first-line fighter and fighter-attack aircraft, along with closely related prototypes, technology demonstrators, and fighterlike unmanned flying vehicles. Development of medium and heavy bombers is also touched on, par-

[5]Lorell (1995). Much of the introductory material in this and the following chapters, as well as the overall conceptual structure of this book, is the same or similar to that found in that companion report.

ticularly where there appears to be a close relationship between the design and technology challenges posed by the two types of aircraft. Less attention is devoted to military transports, specialty aircraft, trainers, missiles and space vehicles, commercial aircraft, and so forth, although they are considered.

Most important from the industrial perspective, the skills and knowledge base necessary to develop fighters (and bombers, to a somewhat lesser extent) are unique in important respects. Broad, generic design methodologies, technologies, processes, and management approaches are applicable to many types of aircraft and other aerospace products. But the performance and technological demands confronting developers of modern jet fighters and bombers usually far exceed those of contemporary commercial transports and many other types of aircraft—in design, materials, avionics (radars and other electronics), engines, system integration, and other important aspects. First-line jet fighters are among the most demanding and technologically challenging types of military fixed-wing aircraft to design, develop, and integrate. Fighters are relatively small, densely packed, very-high-performance aircraft optimized for high speed, maneuverability, the effective delivery of air-to-air and air-to-ground munitions, and, more recently, stealthiness. Historically, the performance requirements generated for new fighter designs have often pushed the outer limits of design and engineering knowledge during any given period. Recognizing the importance of ever better performance, prime contractors over the decades have routinely sought to win fighter R&D competitions by proposing radical new designs incorporating novel technological concepts. Skills and capabilities uniquely relevant to these kinds of aircraft have often been critical for the success of these technologically demanding programs.

Compared to fighters, bombers have historically exhibited more central design and technology features in common with large aircraft, such as commercial transports and other types of platforms. Heavy subsonic bombers, such as the Boeing B-47 and B-52 developed in the early 1950s, posed some design and R&D problems similar to those of contemporary fighters, as well as some similar to those of commercial jet transports, military transports, and aerial tankers that were under development at about the same time. However, the Convair B-58 and the North American XB-70 supersonic bomber programs launched in the 1950s provided major technology challenges that differed significantly from contemporary commercial and military transport aircraft development efforts and that in many respects were more akin to those posed by the most advanced fighters of the period, especially in the case of the B-58. Particularly in the 1950s, a clear developmental synergy existed between R&D on supersonic bombers and fighters on the one hand and between subsonic bombers and other large aircraft, such as tankers, military transports, and commercial transports, on the other.

The authors recognize that there are certain methodological limitations to an historical approach to the issues addressed here. Assembling a meaningful sample of cases requires surveying a considerable period covering several decades. Over such a period, the technologies, requirements, acquisition regulations, R&D approaches, definitions of a successful program, and other important factors often change radically. In addition, detailed data on costs, the numbers and experience of engineers at firms assigned to specific projects, and a wide variety of other key program attributes are often difficult to reconstruct with accuracy or even simply no longer available. Nonetheless, an historical analysis can yield important information about the R&D process and the role of experience complementing other research approaches.

This book supplements its historical narrative and analysis with some quantitative data drawn from an extensive database developed by RAND. This database includes nearly all relevant fighter and bomber R&D programs for the periods under consideration. The makeup of this database and how it is used are further discussed below and in Appendix A.[6]

RESEARCH APPROACH AND METHODOLOGY

The central research question of this book is: To what extent does experience help aerospace prime contractors build and maintain credible capabilities in military R&D? To the extent experience does help, extensive prior experience in fighter development and closely related weapon systems and technologies would be critical positive factors for those U.S. prime contractors that succeeded in developing jet fighters that were operationally deployed by the U.S. military.[7]

To investigate this question, the following methodology is used:

- Generate clear definitions of contractor R&D *credibility* and *success.*
- Define and explicate the concept of *experience.*
- Examine historical correlations between *success* and *experience*, using the development of fighters in the United States from the early 1940s to the mid-1990s as the sample.
- Compare and contrast this correlation across differing subperiods characterized by dramatically different technology drivers, procurement environments, and so forth.

[6]Hugh Levaux, building on earlier work led by Giles Smith, is primarily responsible for developing this database.

[7]Although we recognize that important—and innovative—technical contributions can also be made during the production phase, our focus here is on development capability and thus on R&D.

Defining *Credibility* and *Success*

To pursue the research question it is important to define clearly what is meant by *credibility* and *success*. There are no self-evidently obvious criteria for judging and comparing the relative success of R&D programs over a 50-year period in the areas of cost, schedule, performance, and operational success. The variations over this period in procurement regulations, acquisition styles and philosophies, the rates of technological change, the levels of technical uncertainty and risk in development programs, and so forth are too great to arrive at a straightforward list of satisfactory criteria. Therefore, a contractor is simply defined as possessing *credible* capabilities in fighter R&D as follows:

- A contractor has credible fighter R&D capabilities if the governmental customer and the industry press take it seriously when it enters major fighter design, technology demonstration, and/or R&D contract competitions.

A contractor that is *successful* at fighter R&D is defined as one that

- wins one or more major competitive fighter R&D contracts
- completes R&D
- develops a fighter weapon system that the military accepts and operationally deploys.

Industry leaders are defined as those successful contractors that repeatedly win fighter design competitions over time, that satisfactorily complete R&D (weapon system accepted and deployed), and whose fighters are represented in significant numbers in the active fighter inventories of the U.S. Air Force or Navy. Industry leaders are also usually widely recognized by a consensus of the government customers and the industry as a whole during any given period.

For these definitions to be useful for the research question of this study, it must be assumed (at least predominantly) that the company that wins a major competition has been judged primarily on the objective technical merit of its proposed design and its anticipated capability to develop the aircraft successfully. Thus, the best design and the most credible and capable contractor are assumed (predominantly) to win the competition.[8] Although this notion has often been criticized in the popular press and elsewhere, it has never been proven wrong. Indeed, considerable evidence presented here and elsewhere

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[8]No judgment is made on the validity or correctness of the operational and performance requirements the customer generated or on the efficacy of the developmental strategy the government customer adopted.

indicates that military aircraft development competitions are won primarily on merit.[9]

Defining *Experience*

Experience is defined as significant previous design and/or research and development work that exercises and hones skills necessary to design and develop fighters credibly and successfully. To further refine the definition, several important conceptual distinctions are made. They were developed nearly three decades ago by two RAND analysts, Hall and Johnson, in a study of skills and capabilities in the aerospace industry.[10] Hall and Johnson divided aerospace industry knowledge and capabilities into three categories: *general, system-specific,* and *firm-specific. General* aeronautical knowledge and capabilities are those common to the entire industry and necessary for entry into the industry. They run the gamut from basic science and mathematical knowledge to specialized skills, such as toolmaking and computer programming. All active aerospace prime contractors possess this general knowledge and these capabilities above some minimum level to remain active in the industry.

System-specific knowledge and capabilities are those acquired by firms that engage in certain projects or tasks or that design, develop, and manufacture specific types of articles. All or most companies that develop similar items are likely to possess these capabilities. According to Hall and Johnson, they comprise

> ingenious procedures connected with a particular system, solutions to unique problems or requirements, and experiences unlike those encountered with other systems.[11]

This concept implies that not all aerospace prime contractors will possess the same level of system-specific knowledge and capabilities at any given time, because some firms will have knowledge and experience in specific types of systems and others will not. Thus, some firms will be better than others at design-

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[9]It is commonly alleged that economic and political considerations, rather than technical merit, play a central role in the selection of contractors to develop major weapon systems. However, there is little evidence to support this hypothesis. Rather, strategic, bureaucratic, and technological factors may be more important for explaining the selection of winners. A recent academic study demonstrates that

> Political explanations of contracting decisions describe neither process nor outcomes adequately and oversimplify a vastly complicated decisionmaking structure. Indeed, one reason pork barrel explanations are so attractive is that they are simple, parsimonious, and persuasive. They are also mostly wrong. (Mayer, 1991, p. 210.)

[10]See Hall and Johnson (1968).

[11]Hall and Johnson (1968), p. 5.

ing and developing fighters, for example, and hence more likely to win design and development competitions in their areas of specialization. These will be the leading contenders for contracts in any competition for a specific type of system. As our examination of the historical record beginning in Chapter Two shows, the contractors that won R&D competitions for fighters generally had the greatest system-specific experience in fighter development. Clearly, system-specific capabilities are directly related to system-specific experience.

But why does one company with system-specific knowledge sometimes win out over another company with broadly similar system-specific knowledge, often repeatedly? This phenomenon is explained in part by the concept of *firm-specific* knowledge and capabilities. These are defined as those possessed by only one or at most a few among all the companies that make the *same* item. These capabilities "cannot be attributed to any specific item the firm produces" but rather result "from the firm's over-all activities."[12] Thus, even firms that develop and manufacture similar items may have different levels or types of knowledge and capabilities based on the totality of their overall experience, special areas of technological expertise developed through special company-funded R&D efforts, their management and organization, corporate culture, and so on.

This study utilizes the concept of firm-specific knowledge, as defined by Hall and Johnson, and expands on it and refines it slightly by emphasizing the concept of *technology innovation.* The research of this study implies that the most significant firm-specific capabilities arise most often from new technical concepts, approaches, or processes that have been either developed or adopted by a company with a uniquely visionary perspective on potential future developments.

Later in this book, it is argued that firm-specific knowledge, particularly when related to key types of technology innovation, is a critically important concept that plays a central role in the changes in leadership in the industry that take place during periods of great technological ferment. It is concluded that, particularly during periods of great technological change, firm-specific capabilities can be more important than system-specific capabilities.

The historical record includes many instances of both highly innovative firms that lacked system-specific experience in fighters and firms with extensive system-specific experience in fighters that lagged in technical innovation and the development of new firm-specific capabilities. In the end, both types of firms often fell from leadership positions or even left the fighter R&D business entirely. To maintain a position as an industry leader in fighters over the long

[12]Hall and Johnson (1968), p. 5.

run, successful prime contractors often must combine both system-specific capabilities derived from extensive and continuous fighter R&D experience with unique and innovative firm-specific capabilities based on visionary technology-research efforts.

Three Postwar Periods of Fighter R&D

For analytical purposes, this book divides the five decades since World War II into three broad periods of fighter R&D. Each period is characterized by different clusters of dominant technology challenges, military requirements, procurement environments, and technology drivers. These periods are summarized in Table 1.1. Division of the postwar period into these three periods serves as a broad conceptual guideline; there is no distinct, clear-cut beginning or end for any of the three periods. Nonetheless, the periods are dramatically different in several respects and require separate treatment.

The first period covers about 15 years from the mid-1940s to the end of the 1950s. During this period, U.S. military planning was dominated by the prospect of strategic nuclear war and the doctrine of massive retaliation. More importantly, it was a period of revolutionary technological change and innovation, when the government funded large numbers of procurement and technology-demonstration programs. Large numbers of highly capable contractors competed for a rich array of R&D and technology demonstration programs.

Table 1.1

Three Broad Periods of Postwar Fighter Development

Timeframe	Overall Technology and Procurement Environments	Dominant Performance Goals	Technology Drivers
1940s–1950s (1st and 2nd generation)	Technology revolution Many R&D programs Much prototyping Many capable contractors Requirements consensus	Speed Ceiling Rate of climb	Aerodynamics Propulsion Materials
1960s–1970s (3rd & 4th generation)	Technology refinement Fewer R&D programs Less prototyping R&D policy revolution Fewer contractors Requirements debate	Maneuverability Agility Flexibility Multirole	Avionics System Integration Propulsion
1970s–1990s (5th generation)	Technology revolution Fewer R&D programs Increased prototyping Fewer experienced contractors Requirements consensus	Stealth	Airframe shaping Materials Avionics

The second period stretches from the beginning of the 1960s into the mid-1970s. It is characterized by a dramatic decline in the number of new program starts, caused primarily by rapidly rising R&D and procurement costs. Early in the Kennedy administration, Defense Secretary Robert McNamara introduced profound changes in government procurement strategies intended to control costs and rationalize the military procurement process. These changes increased the emphasis on multirole and multiservice fighters, which in turn further reduced the number of new program starts and increased R&D program complexity and costs. Later in the 1960s, combat experience in Vietnam and other factors led to a temporary reversal of these trends.

However, they had clearly reemerged once again by the mid-1970s. The emphasis on fighter maneuverability and agility that had arisen in the late 1960s persisted into the 1970s and beyond. While enormous strides in technology and capabilities were made during this period, particularly in avionics and munitions, the changes to the basic airframe-and-engine platform were relatively less revolutionary than those witnessed in the late 1940s and 1950s. Several important contractors withdrew from the fighter R&D business during this period.

Finally, the last period, which spans the mid-1970s to the present, is dominated by the stealth revolution. As in the first period, this period is characterized by revolutionary changes in technology that carry the potential of fundamentally transforming aerial combat.[13]

Database Analysis

The role of experience is further examined through the use of a database RAND developed for this study. The main purpose of the database is to record the historical trends of aerospace R&D experience over time by contractor, aircraft type, and type of R&D.

The database, which is described in more detail in Appendix A, contains descriptive, historical, and numerical information on 223 major fixed-wing military and commercial aircraft R&D programs undertaken by U.S. aerospace contractors between 1945 and 1995. In addition, 341 entries of distinct models and versions of these military aircraft are included in the database.[14] The R&D

[13]An excellent overview of the history of jet-fighter development can be found in Hallion (1990), pp. 4–23. Hallion divides jet-fighter development into six generations: high subsonic (1943–1950), transonic (1947–1955), early supersonic (1953–1960), supersonic, limited purpose (1955–1970), supersonic, multirole (1958–1980), and supersonic, multirole, high efficiency (1974–present).

[14]A program is defined as an R&D effort for a specific aircraft, such as the F-84, F-4, B-1, C-141, Boeing 707, or X-31. Aircraft versions refer to major new models, modifications, or upgrades of the same basic aircraft. Thus, separate data entries exist for the F-4C and F-4E, for example. Radical

programs are divided into eight categories of aircraft, shown in Table 1.2.[15] For most aircraft, the database also distinguishes among four principal phases or types of R&D: (1) design, (2) technology demonstrator or prototype, (3) full-scale development, and (4) modifications and upgrades. In addition, X-plane R&D programs are treated as a separate, fifth category of R&D.[16] Other distinctions are made, such as supersonic versus subsonic, and stealth versus nonstealth.

Experience is measured in terms of the number of programs and their size. Duration of a program is used as a proxy for size. Thus, if three years passed between the time a firm received a fighter prototype development contract and a full-scale development contract for that fighter, that firm is credited with having three years of experience in the technology demonstrator or prototype phase of fighter development. This approach has limitations, of course. Dollar size of programs or numbers of engineers might have been better measures, but limitations in data availability and other factors prevented their use. The approach adopted here, however, does help provide important additional information to the more descriptive approach of evaluating project histories.

Table 1.2

Database Overview

Aircraft Categories	Programs	Aircraft Versions
Fighter	106	171
Bomber	26	48
Reconnaissance	10	20
Trainer	6	11
Military Transport	18	25
Unmanned Vehicle	23	24
Miscellaneous	16	23
Commercial Transport	18	19
Total	223	341

modifications or upgrades, such as the F-84F, the F-86D, or the B-1B, are treated as new aircraft programs.

[15]The database includes fighter-attack and attack aircraft whose official designation begins with an "A," such as the A-4, A-7, or A-10, in the category of fighter aircraft. From the technical perspective, these aircraft are generally much closer to fighters than to heavy bombers. However, the text focuses mostly on fighter aircraft that bear the official "F" designation and discusses attack aircraft only peripherally.

[16]This category includes the X-1 through the X-31 aircraft that are relevant to this study. X-planes are intended for proof testing of one technology or set of technologies, and are seldom meant to be developed into operational aircraft. XF and XB programs are treated as technology demonstrators or prototypes because such programs are usually meant to have the potential of entering into full-scale development and becoming operational aircraft. All X-planes are assigned to one of the eight aircraft types shown in Table 1.2.

The database also has limitations in that data sources varied considerably in quality and detail, and more information is included on fighters and bombers than on other types of fixed-wing aircraft. However, virtually all jet fighters, fighter-attack aircraft, and bombers developed and flown by U.S. industry since 1945—as well as all fighter and bomberlike prototypes, technology demonstrators, and X-planes—are included. Most major modifications, upgrades, and significant new models of existing fighters and bombers are also included.[17]

Fighters account for about 40 percent of all the programs in the database and nearly 50 percent of the aircraft versions. However, because most of the other categories of fixed-wing aircraft—particularly for those aircraft most closely related to fighters—are represented, the great diversity of experience that U.S. prime contractors have accumulated over the past 50 years of aircraft development is fairly accurately reflected. Analysis that draws on this database appears in the concluding discussions about each of the three main eras of fighter R&D.

CONCLUSIONS

Based on the methodology described above, the remainder of this paper surveys postwar fighter development for evidence on the importance of experience in development capability. A preview of the conclusions is presented below:

- Experience matters. Prime contractors tend to specialize and thus to develop system-specific expertise. For most of the period under consideration, successful contractors built on a clear and uninterrupted progression of related R&D programs, as well as design and technology projects. A strong experience base in specific types of military aircraft R&D or in specific technology areas appears to have been extremely important. Special measures for maintaining the experience base may be critical for a viable aerospace industry capable of meeting future military requirements.
- The historical evidence indicates little correlation between expertise in commercial transport development and successful fighter R&D. However, there appears to be a strong link between expertise in fighter development and bomber R&D. Therefore, commercial aircraft development programs

[17]Although we believe the database is one of the most extensive in existence, a variety of data limitations and other constraining factors resulted in numerous gaps. For example, a few "letter" models of specific types of fighters were not included, because insufficient data were available in published sources or for other reasons. One well-known "letter" model—the F-4G—is not included because this model was entirely derived from rebuilding existing airframes of other variants. The database has no separate entries for different "block" versions of fighter aircraft, even though some block versions vary significantly from each other, such as the F-16C/D Block 40 compared to the F-16C/D Block 50. Data on military aircraft other than fighters, attack aircraft, and bombers are considerably less complete. Many but not all large commercial transports are included.

are unlikely to provide the necessary experience base for future military aircraft R&D programs.

- During periods of normal technological evolution, high intraindustry entry barriers prevent prime contractors from changing their areas of specialization, further suggesting the importance of system-specific expertise. During periods of radical technological change, however, entry and success in new areas of specialization take place, causing major changes in R&D leadership. Much of the dynamism in military aircraft technology in the past appears to have been promoted by intense competition among many firms, each driven to risk dramatic new technological approaches to increase its market share. This then implies that a dynamic military aircraft industrial base may require more than two or three prime contractors or specialized divisions.
- Over the past 50 years, dedicated military R&D conducted or directly funded by the U.S. government has been **critical** in the development of new higher-performance fighters and bombers. Major new breakthroughs in combat aircraft technology, design approaches, and concepts have come far more often from government labs or government-sponsored military R&D carried out by military contractors than from the commercial sector. As a result, the contribution of commercial technology to future military aircraft design and development may be limited, at least on the overall system level. However, the contribution of commercial technology and manufacturing processes could be significant, especially on the parts, components, and subsystem levels and in the area of electronics.

The following chapters describe the historical record of postwar fighter development in detail, and describe how this record relates to the above conclusions.

Chapter Two

THE 1920s TO THE 1950s: THE LONG ROAD TOWARD U.S. LEADERSHIP IN FIGHTER R&D

INTRODUCTION

The first era of jet-fighter development extends from the mid-1940s through the beginning of the 1960s. During this period, the introduction and refinement of the turbojet engine led to a major technology revolution in fighter R&D. The performance, weight, complexity, and cost of fighters dramatically increased. For the first time in history, American companies took the unquestioned lead in world fighter technology development.

During the first decade and a half of the jet age, contractors developed America's first and second generations of jet fighters and bombers, while nearly all other military aircraft, as well as commercial transports, began transitioning from piston engines to jet or turboprop propulsion. The era was characterized by rapid technological evolution and innovation, particularly in airframe design, materials, and avionics and in aircraft propulsion. The U.S. government funded a remarkable array of fighter and bomber R&D programs ranging from full-scale development of new operational aircraft to technology demonstrators or prototypes. More than half of all the experimental X-planes developed by U.S. industry since World War II began development before 1960. Indeed, more military aircraft designs were developed and reached first flight during the 1950s than in all the following four decades combined.[1] If fighterlike X-planes are counted as fighters, nearly 70 percent of all postwar jet-fighter programs took place between the end of World War II and 1961 (see Appendix A).

Figure 2.1 provides an overview of jet-fighter R&D and related programs for the 1940–1961 period. Contractors who developed fighters during this period are placed into three categories: the "first tier" of leading developers of fighters for the Air Force; the "second tier," or relatively less important developers of Air

[1]Drezner et al. (1992), p. 28.

Force fighters during this period; and contractors that focused on development of Navy fighters.[2]

For the most part, the U.S. companies that had emerged from World War II as the leaders in prop-driven fighter R&D were able to build successfully on their extensive system-specific experience while absorbing and developing the new technologies and skills required to exploit the enormous potential of jet engines. Some new entrants also fared well because of the relatively high levels of government spending on military R&D and because the rapid pace of technological change permitted innovative companies with special firm-specific skills to break into the market. Most American companies adapted well to the jet revolution, in part because of the vast expansion in industry structure and capabilities that occurred during World War II.

This chapter first briefly reviews fighter development in the United States before World War II. This review shows how another technology revolution in the 1930s and the vast production contracts and wide-ranging wartime R&D efforts of World War II helped establish the foundations for the industry leaders of the mid-1940s who ushered in the jet-fighter era and made U.S. leadership in fighter R&D possible. It then examines the development of America's first generation of jet fighters during and immediately following World War II. Chapter Three then turns to the dramatic technological jump to supersonic fighters that took place in the 1950s, which led to a major increase in weight, complexity, and cost of fighters and ultimately resulted in the McNamara reforms of the early 1960s and the restructuring of the fighter aircraft industrial base.

U.S. FIGHTERS AND THEIR DEVELOPERS BEFORE THE JET AGE (1917–1945)

Although Americans pioneered the development of heavier-than-air flying machines, European countries soon wrested technology leadership away from the United States.[3] Indeed, U.S. aircraft manufacturers soon fell so far behind the Europeans that they did not design and develop any fighters used in combat during World War I. U.S. fighter squadrons that deployed to Europe flew

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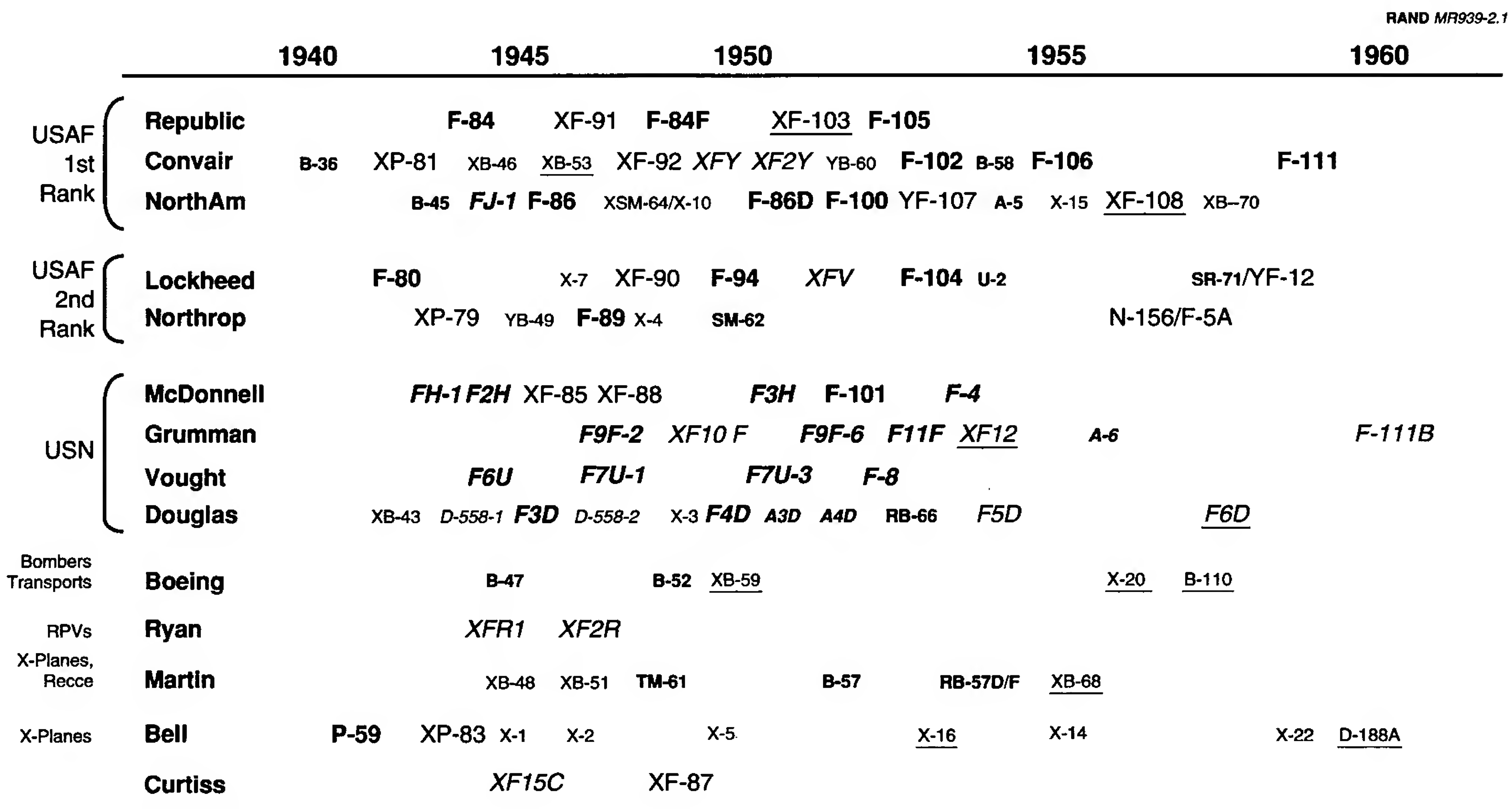
[2]The rationale for placing Air Force fighter contractors into two tiers is the substantial difference between the two groups in the numbers of design competitions won for Air Force fighters and the significant differences among contractors in the two tiers in the numbers of distinct Air Force fighter types developed and put into production. For the details, see the "Experience and Specialization: The Continuity of Leadership" section in Chapter Five.

[3]This account of early U.S. fighter development is based on Munson and Swanborough (1970), pp. 7–15; Green and Swanborough (1994), passim; Gunston, (1978), passim; and Bright (1978), pp. 1–10.



SOURCE: RAND database.

Large type = fighters; small type = other fighter related (attack, bombers, cruise missiles, experimental, etc.); bold = procured; italics = Navy program; underline = cancelled before 1st flight.

NOTE: Aircraft placement approximates beginning of full-scale development. Not all programs shown here are included in the database.

Figure 2.1—Jet Fighter, Bomber, and Related R&D Programs, 1940–1961

foreign-designed fighters, such as the famous French SPAD S.XIII and the Nieuport 17.[4]

In the later phases of the war, American companies began planning to produce French and British fighter designs under license. However, U.S. officials soon dropped these plans in favor of indigenous design and development. The National Advisory Committee for Aeronautics (NACA), forerunner of the National Aeronautics and Space Administration (NASA), was established in 1915 to help America regain aeronautical technology leadership. By the early 1920s, American companies had begun designing and producing competitive fighter aircraft. Yet up through World War II, the United States continued to depend heavily on foreign countries to conduct the basic research and provide most of the significant technological breakthroughs in aeronautics. U.S. industry drew most of its important aerodynamic, configuration, design, and structural concepts during this period from German sources, supplemented by developments from Britain, Italy, Russia, and Japan.[5] This reliance on foreign countries should not overshadow, however, the important breakthroughs developed under NACA's auspices—e.g., cowlings and variable-pitch propellers—or breakthroughs pioneered independently by U.S. firms—e.g., multispar wings—all innovations that were adopted by every aircraft developer by the late 1930s.

Although many significant technological innovations appeared over the decade and a half following the end of World War I, the basic fighter design concept and configuration as established during the war changed little in the 1920s and early 1930s. Fighters during this period remained open-cockpit, single-seat, single-engine biplanes with two or four fuselage-mounted machine guns firing forward through the propeller arc. In addition, procurement numbers, and thus the size of the market and the industry that arose to meet its needs, remained extremely small. Out of the roughly 1,400 aircraft in service with the U.S. Army Air Service in mid-1924, less than 80 were fighters.[6] Through the

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[4]The only widely used U.S. military aircraft to emerge during the war was a trainer and general-purpose aircraft developed by Curtiss called the Jenny. SPAD was an acronym for *Société Anonyme Pour l'Aviation et ses Dérivés*, which was the name the prewar Deperdussin company adopted in 1915. SPAD designed and built some of the best and most famous fighters of World War I. Nieuport was the other most famous French firm. The German firm Fokker, which developed the renowned D.VII biplane and Baron Manfred von Richthofen's famous red Dr.I triplane, earned the distinction of being perhaps the most famous World War I fighter manufacturer. After the war, the restrictions of the Versailles Treaty forced Fokker to move its operations to the Netherlands. Leading British fighter developers during the war were Sopwith and the Royal Aircraft Factory.

[5]See Bright (1978), p. 8.

[6]Fighters in U.S. service were called pursuit aircraft and designated with a "P" instead of an "F" from the 1920s through the late 1940s. The "P" designation was changed to the "F" designation for all U.S. fighters in 1948.

early 1930s, the Army and Navy together fielded a total of only five permanent first-line fighter squadrons.

Because all aircraft were relatively small and simple and total production runs of any single type remained quite small, few successful companies in the 1920s and 1930s specialized primarily in fighters or even the much broader category of military aircraft in general. Nonetheless, the Curtiss Corporation emerged very early as the most prolific developer of successful fighters and remained the industry leader through the late 1930s. The fighters of its extensive Hawk series were among the most important combat aircraft of the era and served as first-line fighters for both the Army and the Navy in the 1920s and 1930s. Achieving considerable success with its F4B/P-12 and its famous P-26 "Pea Shooter," Boeing also became a leading fighter developer for both services during this period. Founded in 1929, Grumman Aircraft Engineering Corporation rapidly won wide recognition for Navy fighter development with its innovative FF-1, which featured retractable landing gear and a fully enclosed cockpit. Other somewhat less successful fighter developers of this period included Consolidated (later General Dynamics), Douglas, Lockheed, Northrop, Vought, and Vultee.

In the mid-1930s, an accumulation of major technological innovations led to a "mini" technology revolution that dramatically altered fighter aircraft for the first time since World War I and greatly increased their performance. The all-metal, monocoque, low-wing monoplane fighter developed at this time with retractable landing gear, enclosed cockpit, and guns in the wing quickly rendered the conventional biplane fighter obsolete. The rapid changes in technology and configuration at this time reduced the relative importance of the experience with the old technologies and configurations possessed by the industry leaders, such as Curtiss and Boeing, and opened the field for new entrants. At the same time, the gathering war clouds in Europe and Asia spurred major rearmament programs in the United States and abroad, thus greatly expanding the market and increasing the financial incentives for new entrants. New or marginal companies lacking reputations and experience in fighter R&D sought to garner R&D contracts in competition with the established companies through even greater technological innovation and risk-taking.

Almost overnight, small, marginal, and even entirely new companies—or established companies that had not competed seriously before in fighter R&D—became major contenders. Thus, the little-known Seversky company (later Republic), founded only a few years earlier, won a major fighter competition in 1936 by beating a Curtiss design. Seversky went on to develop the P-35 successfully, the U.S. Army Air Corps' (USAAC) first single-seat monoplane fighter with retractable landing gear and enclosed cockpit. A totally new entrant—the Brewster company, which had been founded as a carriage manufacturer in

1810—began competing in the military aircraft business in 1935 and actually beat Grumman a few years later in a competition for the Navy's first monoplane carrier fighter. Lockheed, a small company that had become a recognized developer of commercial transports but had never successfully developed a military design, won a 1937 USAAC competition for a long-range fighter with a radical twin-boom design, which later became the famous P-38 Lightning. Founded only in 1935, Bell developed a highly innovative and unorthodox twin-engine FM-1 prototype and the unusual mid-engine P-39 Airacobra fighter with company funds. The P-39 Airacobra was later procured by the U.S. Army Air Force (USAAF)[7] and foreign countries in huge numbers.

The former industry leaders did not necessarily just fade out from the fighter business in this rapidly expanding market, however. While Boeing committed much of its corporate resources to developing a long-range strategic bomber (the famous B-17 Flying Fortress), Curtiss remained active in fighters. Curtiss continued development of its Hawk 75 design, which had lost to Seversky's P-35. It was later procured as the P-36, and then modified into the famous P-40 Warhawk. Grumman continued development of its XF4F-2, which had lost the Navy competition to the Brewster Buffalo. Later, the Grumman model evolved into the famous F4F Wildcat, which became the standard aircraft-carrier-based Navy fighter in the early stages of World War II.

It was also during these last years before Pearl Harbor that some of the later legends among U.S. fighter contractors first considered entering the field. North American Aviation, established in 1935 and known only for its sturdy little basic trainer, began contemplating entry into the fighter market and even modified its USAAC NA-16 trainer into simple lightweight fighters called the NA-50 and NA-64. As an even longer shot at the new market, James McDonnell, chief engineer at Martin and designer of several innovative Martin bombers, quit his job in mid-1939 and set up a tiny new company in St. Louis named after himself. Over the next year, he and his small team of engineers submitted 12 proposals to the USAAC and four to the Navy, most of which were for novel new fighter designs. All were rejected.[8]

On the eve of Pearl Harbor, it still remained unclear which companies would emerge as the new leaders in development of the modern fighter types that had resulted from the mini technology revolution of the mid-1930s. The Lockheed P-38, Bell P-39, Curtiss P-40, Grumman F4F, and Brewster Buffalo were the most modern U.S. Army and Navy fighters in the active inventory when the war started. Yet with the exception of the P-38—which was available in only very small numbers at the beginning of the war—these fighters were generally out-

[7]The U.S. Army Air Corps became the U.S. Army Air Force on June 20, 1941.

[8]Francillon (1990b), p. 6.

classed by the leading Japanese and German fighters against which they had to fight. None of these fighters—except for the P-38—remained in production in the later stages of the war.[9]

Some companies—both former leaders and new entrants—ultimately did not fully succeed in the new fighter R&D competition, which was launched by the mini technology revolution of the mid-1930s and reached its climax during World War II. They would fail completely during the much more dramatic technology revolution wrought by the jet engine after the war. These would include the single most important leader of the 1920s and 1930s—Curtiss—as well as new entrants, such as Brewster and Bell.[10]

By the end of World War II, North American, Republic, Lockheed, Grumman, and Vought had clearly shown the most skill and innovation at exploiting the new prop-fighter technologies first developed in the mid-1930s and thus had emerged as America's most successful fighter developers and manufacturers. Lockheed's famous two-engine P-38 played a critical role in winning air superiority in the early stages of the war and remained in production throughout the conflict. The majority of observers would agree that the most successful conventional Army Air Force fighters of the war were the North American P-51 Mustang and the Republic P-47 Thunderbolt. With a total production run of 15,683, the P-47 was the most heavily produced U.S. fighter of the war and was used with great success in every theater of the war except Alaska. Although it enjoyed a slightly smaller production run of 14,855, the P-51—especially the "D" version—is usually considered America's best mass-produced fighter of the war. Because it was the Navy's first carrier-based fighter to clearly outclass the Japanese Zero, Grumman's F6F Hellcat contributed significantly to turning the war around in the Pacific. The high-performance Vought F4U Corsair is also considered one of the great fighters of the war and continued to be produced for many years after the war ended.

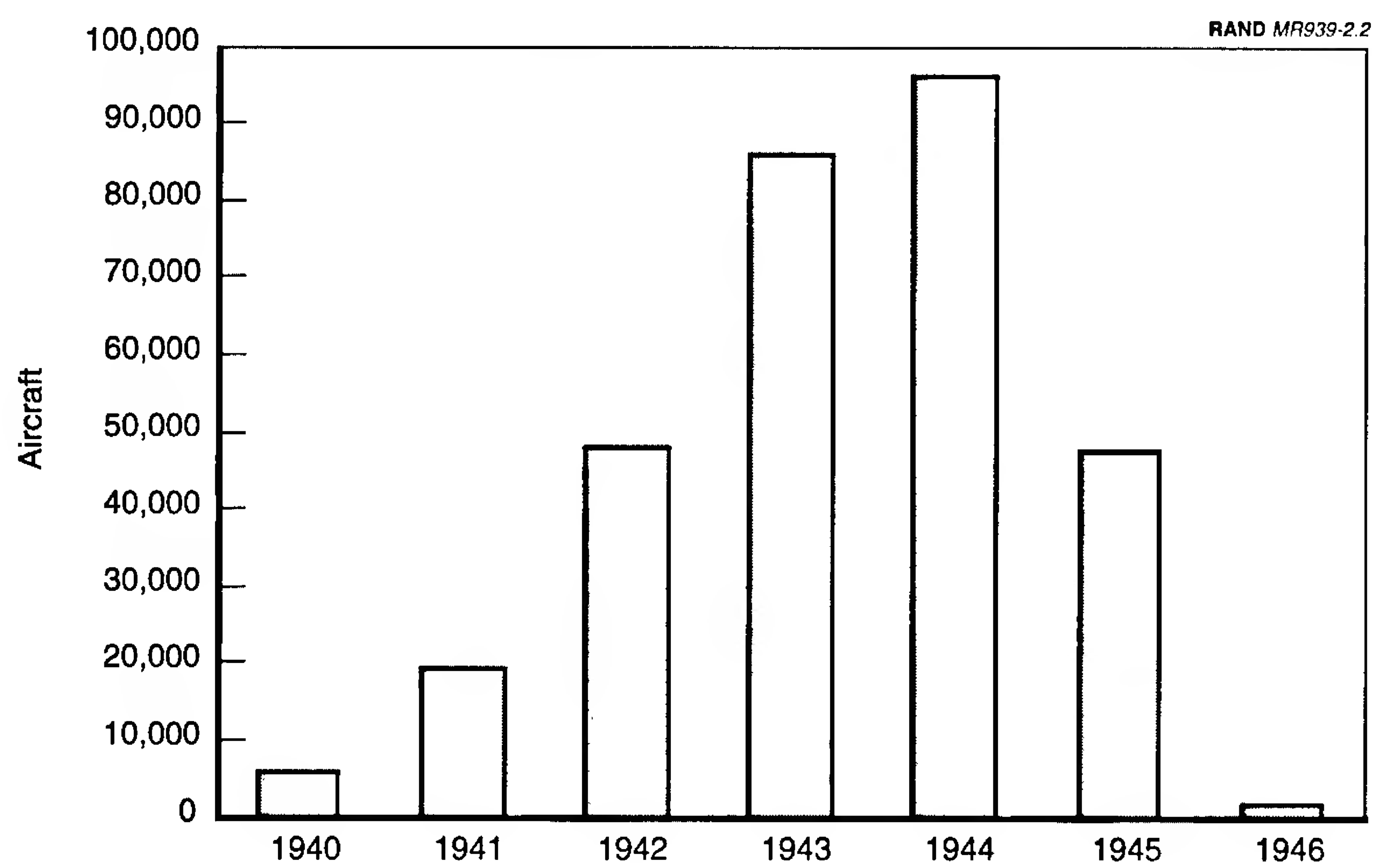
Republic (Seversky), Grumman, and Vought had all had significant fighter R&D experience before the war, while North American and Lockheed had had little or none. None of these companies, except Grumman, had been important

[9]Well into 1943, most USAAF fighter pilots in the Pacific were equipped with P-39s and P-40s, while Navy and Marine pilots flew mainly F4Fs and Buffaloes. The Japanese Mitsubishi A6M Zero could easily outclimb and outmaneuver any of these aircraft, had heavier armament (two 20mm cannons), and a much longer range. The only advantages the U.S. aircraft possessed were that they could outrun the Zero in a dive and were better protected with armor plate and self-sealing fuel tanks. As a result, the Japanese essentially retained air superiority in most theaters until the P-38 Lightning, F4U Corsair, and F6F Hellcat began entering service in significant numbers in 1943. See Yoshimura (1996). The Brewster Buffalo ended the war with a particularly poor reputation in the United States. However, recently published research suggests the basic design was actually quite competitive. See Ford (1996).

[10]Although Bell went on to a very successful business building helicopters, Curtiss and Brewster were no longer aerospace prime contractors by the 1950s.

fighter developers until the mini technology revolution of the mid-1930s helped break the hold of Curtiss and Boeing on the market—and Grumman had been an early pioneer of key changes that led to the revolution. Curtiss had failed to adapt well to the new technological environment, while Boeing's resources had essentially been diverted to heavy bomber development, especially once the high-priority and very technologically demanding B-29 program had gotten under way during the war.[11] Thus, system-specific experience seems to have played a critical role in the 1920s through the mid-1930s, when Curtiss and Boeing continued to dominate the fighter market. But with the dramatic technology changes of the mid-1930s, firm-specific capabilities and the ability to innovate clearly became more prominent.

World War II also radically changed the very structure and nature of the American aircraft industry. The gigantic production runs demanded by World War II, as shown in Figure 2.2, transformed the aircraft business from the small-scale specialty industry of 1940 into the largest mass-production heavy industry



SOURCE: Stoff, 1993.

Figure 2.2—Annual U.S. Military Aircraft Production During World War II

[11]During the war, Boeing developed and flight tested an advanced piston fighter prototype with contra-rotating props for the Navy, called the XF8B-1. R&D proceeded slowly, however, as Boeing's resources became ever more heavily committed to development of the B-29 and other bombers. When the war ended, the Navy canceled the XF8B-1 program, thus grounding the last flying fighter for which Boeing acted as the prime.

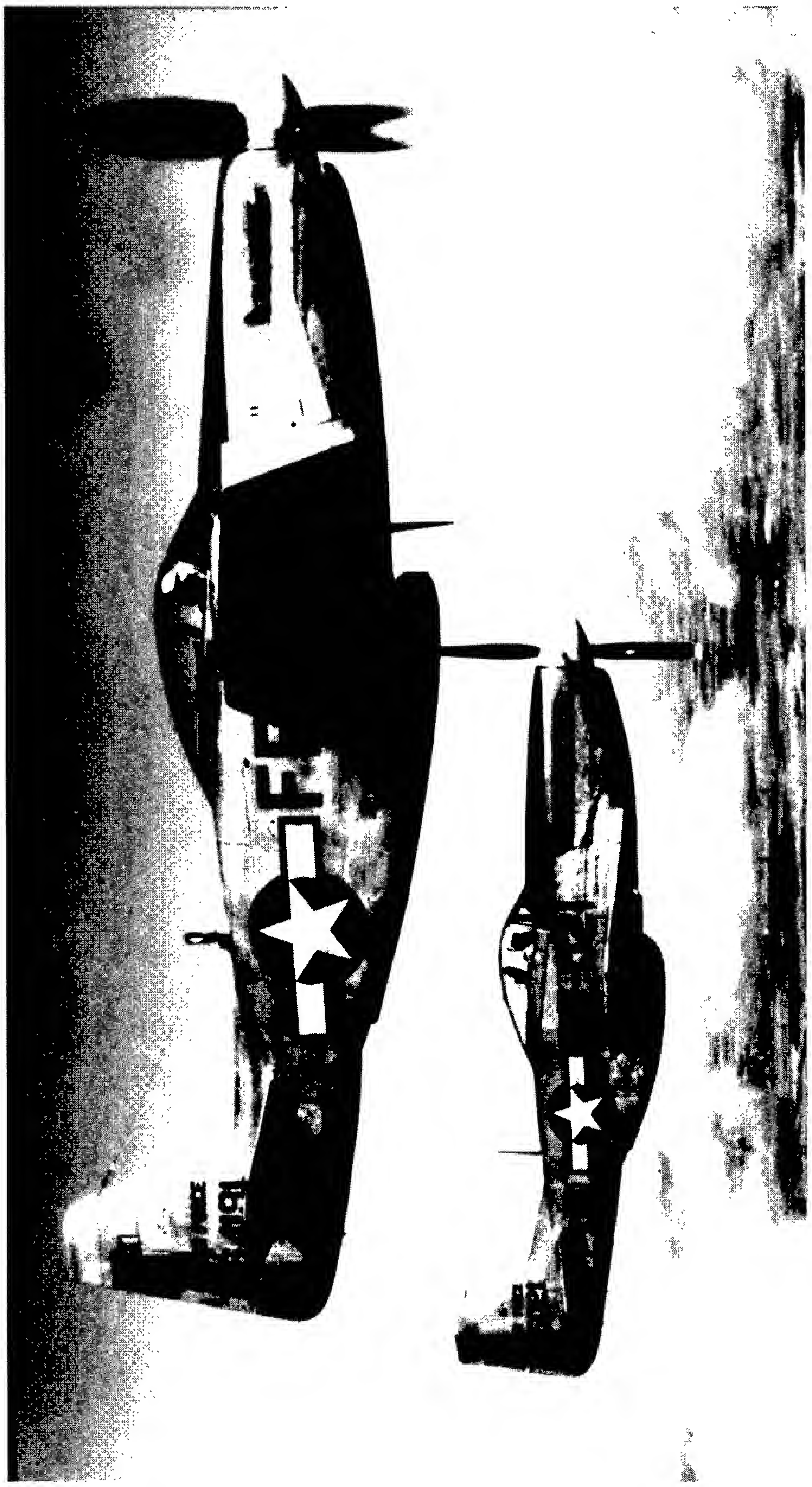


Photo 2.1—Many observers consider the North American P-51 Mustang to have been the most capable mass-produced American fighter of World War II.

Photo 2.2—With a total production run of 15,683, the Republic P-47 Thunderbolt was the American fighter produced in the largest numbers during World War II.

in the United States by 1944. Before 1940, typical total production contracts ran in the tens of aircraft. During the war, production runs of 10,000 aircraft or more were not uncommon. Pioneering engineers like Martin, Douglas, and Lockheed, who ran companies single-handedly before the war, were soon replaced or superseded by legions of young managers in large management structures supported by extensive engineering and technical staffs. Thus, the basic structure of the industry as it existed through most of the Cold War only emerged during the huge wartime mobilization and expansion of World War II.

U.S. industry had helped win the war primarily by massively outproducing both Germany and Japan, not by developing and applying the world's cutting-edge aeronautical technologies. By 1943, U.S. government planners had selected a small number of competent, robust military aircraft designs on which to standardize production.[12] The emphasis was placed on refining these existing designs while maximizing output. Thus, although U.S. industry produced some of the best operational fighters of the war, America had actually fallen even farther behind several other countries in advanced aeronautical technology and innovation during the war, especially Germany and the United Kingdom.

The U.S. industry leadership positions newly established during World War II would not necessarily be maintained easily in a world of even more rapidly changing technology. Only a decade after the mini technology revolution of the mid-1930s had contributed to the emergence of new leaders in fighter R&D, an even more dramatic technology revolution was about to take place, which centered on jet propulsion and very-high-speed flight. For the most part, U.S. companies in 1945 were not initially well positioned to take leadership roles in the new technologies, most of which had been developed in Germany and the United Kingdom. But in the end, the organizational and structural changes in the industry and government wrought by World War II would help U.S. companies with the right mix of system- and firm-specific capabilities to meet the challenge and to help America move toward world leadership in fighter R&D.

BUILDING THE EXPERIENCE BASE: FIRST-GENERATION SUBSONIC JET FIGHTERS

The period from the mid-1940s through the early 1950s can be best characterized as a time of particularly rapid and dramatic technological advancement and change, as developers exploited the enormous increases in potential performance made possible by the jet engine. In this era, innovation, new ideas, and experimentation predominated, particularly in the immediate postwar

[12]More than three-quarters of total wartime military aircraft production took place from 1943 on. Only 19 models of military aircraft made up nearly 90 percent of that production. Total wartime military aircraft production stood at just under 300,000. See Bright (1978) and Stoff (1993).

years—when relatively new firms and established industry leaders had to struggle and fiercely compete to survive in a peacetime world in which the gigantic production orders of World War II no longer existed. While important changes in industry leadership took place during this period, the industry leaders in fighter R&D that had emerged during World War II continued to remain prominent. At the same time, relatively new entrants were able to take advantage of rapidly advancing technology also to rise to leadership positions.

U.S. Jet-Fighter Development During World War II

Serious U.S. efforts to develop an operational jet fighter began in earnest during World War II, but initially progressed slowly. As noted earlier, the American aviation industry helped win World War II largely through mass production of prodigious quantities of a few outstanding but relatively conventional prop fighter designs that were continually improved incrementally. America's relatively slow entry into the jet age resulted in part from this mass-production strategy and the failure of some firms to transition successfully to the radical new technology.

The Army Air Corps did, however, take an early interest in jet fighters even before U.S. entry into the war and continued to push forward jet-fighter development as the war progressed. Not surprisingly, the Air Corps handed initial responsibility for jet-fighter R&D to two leading, and seemingly highly innovative, fighter developers of the time: Bell and Lockheed. In 1941, the Curtiss P-40 and the unconventional Bell P-39 were the backbone of the USAAF fighter force. Bell was continuing to examine unorthodox designs and configurations. The USAAF asked Bell in September 1941 to develop a jet-fighter design to take advantage of jet-turbine technology developed by the British. The Bell XP-59, which first flew one year later, proved to be unsatisfactory in speed and other performance characteristics. Less than a year later, however, Lockheed received the go-ahead to develop a second jet fighter. Not only was the Burbank company's unorthodox P-38 design proving highly successful at this time, but Lockheed engineers had also been independently examining jet-fighter and engine designs since at least 1940.[13] A mere 143 days after the Air Force let the contract, the first Lockheed XP-80 made its maiden flight at Lake Muroc, California.[14] Performance proved exceptional, and plans were made in 1944 for a large production run at Lockheed and North American facilities.

Several other jet fighters began development during the war. Following up on the great success of its P-47, Republic began work on the XP-84 jet fighter late in

[13]Ingells (1973), p. 87.

[14]Later Edwards Air Force Base.

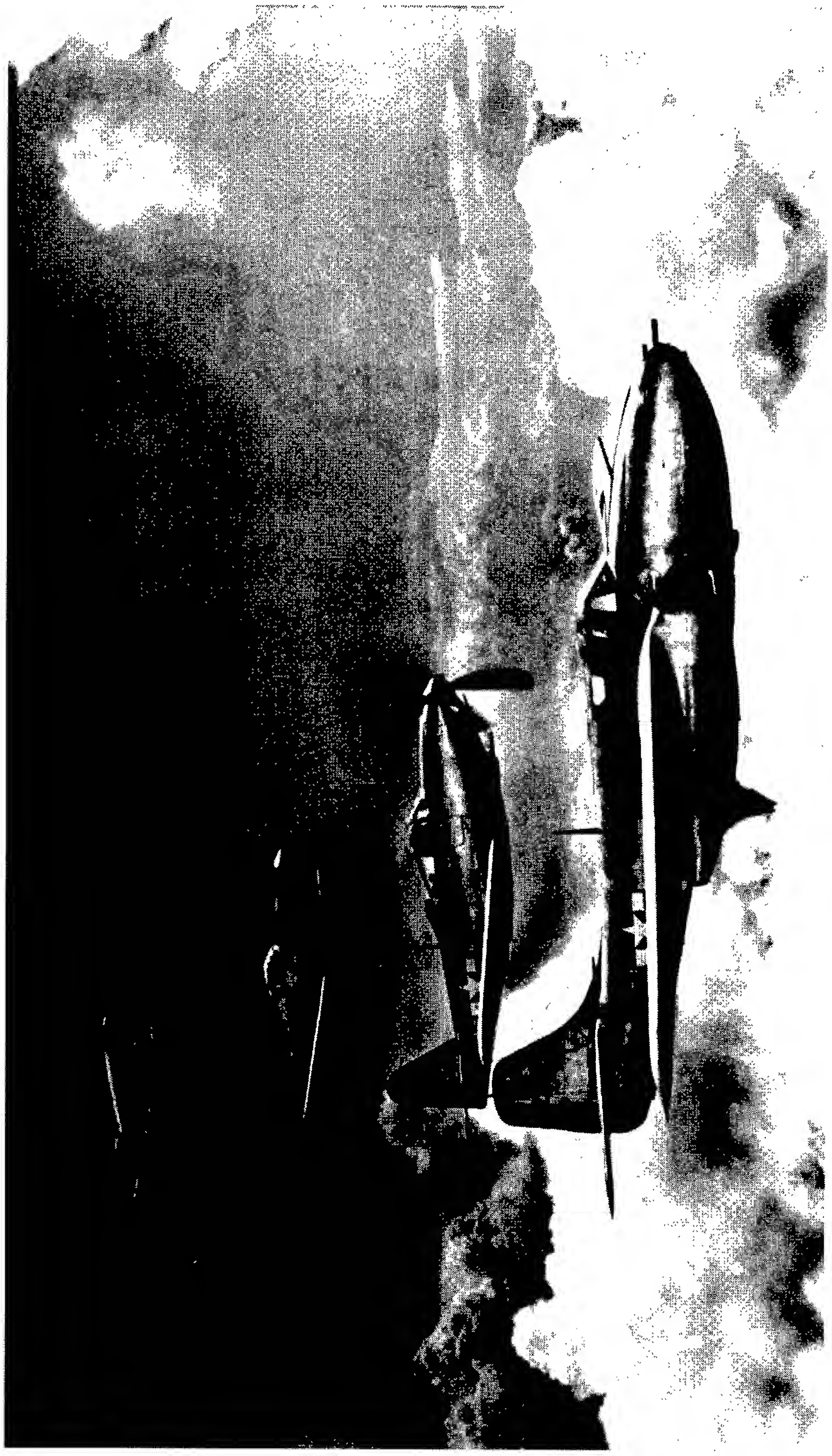


Photo 2.3—The Bell P-59 Airacomet (foreground) was America's first operational jet fighter. First flown in October 1942, the P-59 proved to be a disappointment because of its relatively slow top speed. Behind the P-59 (front to back) can be seen three other World War II Bell fighters: the P-63 King Cobra, the famous P-39 Airacobra, and the little-known lightweight XP-77.

Photo 2.4—The Lockheed P-80 Shooting Star was America's first truly successful operational jet fighter. The XP-80, shown above, first flew in January 1944.

1944. North American, whose P-51 became the most admired mass-produced USAAF fighter of the war, also received a contract near the end of the war to develop the XP-86. This fighter, which later evolved into the famous F-86 Sabre Jet, started life as a slight modification of the FJ-1 jet-fighter design under development for the Navy. However, neither of these highly successful Air Force jet fighters flew until after the end of the war. Convair[15] and Bell also developed USAAF jet prototypes during the later stages of the war (the XP-81 and XP-83, respectively) that unsuccessfully attempted to solve the problem of designing a long-range jet escort fighter with first-generation jet engines that had very high fuel consumption.[16] Thus, the Lockheed P-80 remained the only successful U.S. jet fighter that flew during World War II, and it never saw operational combat service during that conflict.

The U.S. Navy remained more skeptical about jet fighters than the Air Force and was thus slower to initiate jet-fighter development. The relatively short takeoff space available on carrier decks, combined with the low thrust ratings of first-generation jet engines, caused most of the Navy doubts about jet fighters. As a result, the Navy tended to turn to its "second-string" companies with less experience in Navy fighter R&D to initiate the process. This was also because the Navy's leading contractor, Grumman, was overwhelmed with war work, and because the Navy believed that newer companies, or those less well established in Navy fighter R&D, might be more innovative in dealing with the new technologies and designs.[17] This view was borne out by one early contract for a jet fighter, which went to a Navy leader—Vought—in September 1944. Although Vought's prop-driven F4U Corsair was perhaps the best U.S. carrier fighter of the war, the company's F6U Pirate jet fighter, according to the official Navy evaluation, proved so "submarginal" in performance that combat utilization was "not feasible."[18]

The Navy's very first jet-fighter R&D contract, however, went to a virtually unknown company that had been in existence for only three and a half years and had never developed a Navy fighter or any other type of military aircraft that had been purchased in quantity. However, the company had produced a very innovative prop-fighter prototype for the USAAF called the XP-67. That company—the McDonnell Aircraft Corporation—received an R&D contract for

[15]In March 1943, Consolidated Aircraft merged with Vultee Aircraft to become Convair.

[16]The XP-81 sought to combine prop and jet-propulsion systems on one aircraft to solve the range problem.

[17]Swanborough (1968), p. 281.

[18]Quoted in Green and Swanborough (1994), p. 588. This experience paralleled that of the Air Force's with its first attempt at developing a jet fighter with the Bell P-59.

the Navy's first jet fighter, the FH-1 Phantom, in January 1943.[19] North American, another young—though highly successful—company that had never developed a Navy fighter, won an R&D contract for a carrier-based jet fighter on January 1, 1945. As previously mentioned, the Air Force later selected a modified version of North American's Navy jet, designated the FJ-1 Fury, as the basis for the P-86 (later F-86). None of these Navy jets, however, flew before the end of the war.

Production orders for the one U.S. jet fighter that had entered series production during the war—the Lockheed P-80—were slashed soon after the war ended. The U.S. aviation industry in general experienced a severe downturn in sales in the immediate postwar years, as the government canceled the huge wartime production contracts and as the rapidly contracting armed services flooded the world market with surplus transports and other military aircraft. The one bright spot was the continuing intense Air Force interest in further development of jet combat aircraft and associated technologies. The U.S. Navy remained highly skeptical about the practicality and effectiveness of jet combat aircraft, particularly for use on aircraft carriers. USAAF pilots, however, had encountered German jet fighters and bombers in combat over Europe in the last phases of the war. This unpleasant experience helped focus the attention of the Air Force leadership on the need to procure the most advanced and capable combat aircraft possible for any future conflicts.[20]

Furthermore, following the end of the war, U.S. government and aviation industry teams visiting Germany had been shocked to learn just how far German aeronautical and jet-propulsion research had advanced beyond the general level in the United States. While overall *Luftwaffe* procurement patterns during the war had not differed dramatically from the U.S. approach of mass production of conventional designs, the Germans had also invested heavily in radically new aeronautical and propulsion concepts. The first German jet-fighter prototype had flown as early as 1939. Besides the Messerschmitt Me 262, the

[19]For historical accuracy, the Navy mission-manufacturer-number designation system (used until September 1962) is used in the body of this book. Yet, for sorting purposes, the triservice designation system adopted in September 1962 is used in the database. For details about the various designation systems, see Swanborough (1968), pp. 4–18.

[20]See Bright (1978), pp. 11–12. The Messerschmitt Me 262 proved to be Germany's most successful operational jet fighter used during the war. Allied pilots developed a successful strategy to counter this jet by attacking it over its air base during takeoff and landings, when it was most vulnerable. However, during aerial combat, the Me 262 was extremely difficult to defeat, primarily because of its high speed. Even though the Allies had won almost total air superiority when this jet became operational in significant numbers, the Me 262 nonetheless proved highly effective against American heavy bomber formations escorted by large numbers of the latest-model USAAF fighters. One Me 262 squadron alone (*Jagdgeschwader 7 Nowotny*), operating under extremely unfavorable conditions during the last months of the war, claimed around 300 bomber kills and 100 victories against other types of aircraft by the end of the war. See Bavousett (1989), p. 75.

Photo 2.5—The North American F-86 Sabre is considered by many observers to have been the best U.S. fighter to see combat in the Korean War. First flown in October 1947, the F-86 evolved through many variants for both the Air Force and the Navy, many of which remained in service well into the 1960s.

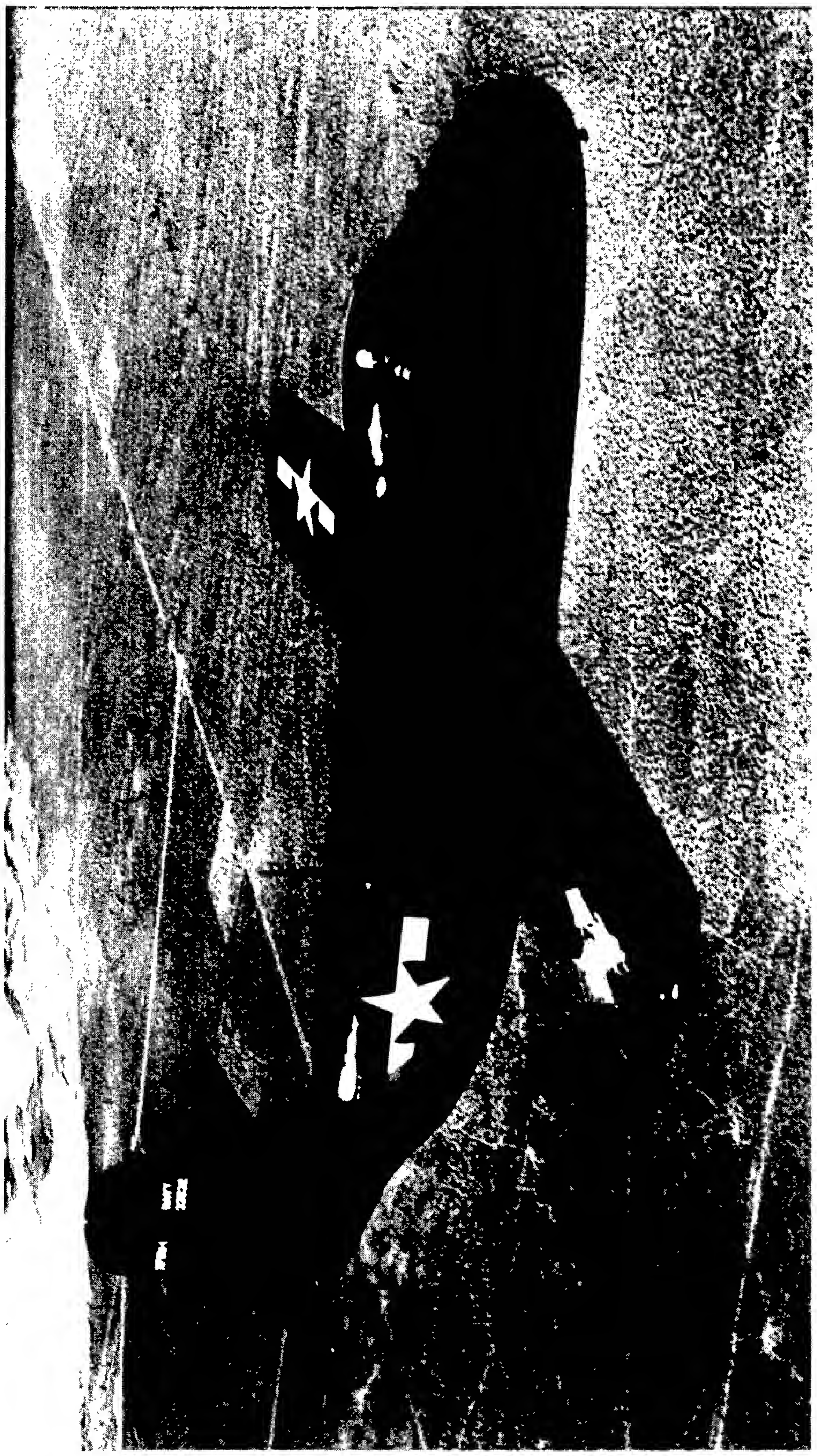


Photo 2.6—With first flight taking place in October 1946, the Vought F6U-1 Pirate was one of the Navy's first jet fighters intended for use aboard carriers. The Pirate performed so poorly, however, that the Navy quickly took it out of service.

highly effective swept-wing jet fighter, the *Luftwaffe* operationally deployed in combat many other radical new aircraft types, including a rocket-propelled tailless fighter (Messerschmitt Me 163) and a jet bomber (Arado Ar 234). Numerous other innovative designs and concepts were under development when the war ended, such as jet bombers with forward-swept wings, flying wings, delta planforms, and vertically launched rocket interceptors. U.S. military and industry representatives realized that the United States had much R&D experience to catch up on to remain competitive in the postwar environment.

Air Force Leadership in the Immediate Postwar Years

Strong Air Force interest in developing new jet-fighter and bomber concepts and technologies spurred intense activity in the U.S. aircraft industry, as contractors—reeling from postwar contract cancellations—competed fiercely for new R&D funding. Engineers poured through captured German data and tried to develop new approaches that would arouse Air Force interest. The three leading wartime USAAF fighter developers—Lockheed, Republic, and North American—held the initial lead in the immediate postwar Air Force fighter market with their F-80, F-84, and F-86 designs. But jet-fighter technologies were so new and evolving so rapidly that nearly all credible aircraft contractors had a reasonable shot at new fighter R&D work and thus entered the fray. Indeed, at one point in the immediate postwar period, the Air Force was simultaneously funding eight jet-fighter and seven jet-bomber R&D programs by a wide range of contractors. In short, during this period, firm-specific experience and capabilities rose in importance relative to system-specific experience, as the Air Force sought new and innovative R&D proposals in a rapidly changing technology environment.[21]

In this fluid and unsettled technology environment, two companies that had not developed successful new single-engine prop fighter designs during the war—Northrop and Curtiss—became the leading contenders for development of the first Air Force "all-weather" long-range twin-engine jet interceptor, one of the first important postwar fighter R&D contracts. Northrop had two major advantages over Curtiss, however. First, Northrop had system-specific experience in this specialized area of fighters. Northrop's only successful wartime fighter had been the P-61, the first night fighter developed from scratch for the Air Force. The P-61 was a heavy twin-engine two-seat fighter packed with a radar and other electronics, which made it similar to the type of fighter now desired by the Air Force. Second, Northrop had experimented with several radical design concepts during the war, such as the jet-powered flying wing XP-79B interceptor. Curtiss, on the other hand, spent the war developing unsuc-

[21]Bright (1978), p. 11.

cessful prop-fighter prototypes, as well as a composite prop and jet Navy fighter prototype that performed poorly.

Northrop's XF-89 design eventually proved successful, and was procured by the Air Force.[22] The Curtiss XF-87 experienced severe aerodynamic problems and other difficulties that the company could not resolve, leading to cancellation of the program in October 1948 in favor of full-scale development of the Northrop F-89. Curtiss, which had already lost its dominant position in fighters after the technology revolution of the mid-1930s, failed completely to transition successfully to the jet-fighter era. The XF-87 was the last Curtiss fighter.

North American, on the other hand, was one of the dynamic new companies that had succeeded spectacularly with the final generation of prop fighters after the mid-1930s mini-technology revolution, then transitioned with great success to the jet era. This young, innovative company was one of the first to recognize the great significance of recently captured German research data on advanced aerodynamics. All early U.S. jet-fighter designs used traditional straight-wing planforms. After studying German research documents, North American engineers concluded early on that swept-back wings would provide dramatic performance improvement in speed without the need to increase engine thrust, by delaying the onset of compressibility effects. In November 1945, the Air Force approved North American's proposal to change its XP-86 design, which it had derived from its straight-wing Navy FJ-1 configuration, to a swept-wing planform. First flown in October 1947, the F-86 Sabre became the most successful and famous American fighter in the Korean conflict in the early 1950s.

Republic also ended the decade of the 1940s in a strong position, as its straight-wing F-84Cs and Ds—the prototype of which had first flown in February 1946—emerged as the most important fighter type in the U.S. Air Force (USAF) inventory.[23] As early as the spring of 1947, however, Republic became increasingly worried about maintaining its preeminent position because of the far superior performance expected from the swept-wing F-86 under development by North American. When the Air Force showed no interest in supporting development of a swept-wing variant of the F-84, Republic went ahead and began design studies of this modification using company funds. Later, the Air Force agreed to sponsor full-scale development. The swept-wing F-84F Thunderstreak made its first flight in June 1950.[24] Although the new fighter eventually proved quite

[22]See Anderson (1976).

[23]In May 1947 the U.S. Air Force was established as a separate military service.

[24]Since the swept-wing modification of the F-84 amounted to virtually an all-new fighter, it originally received a new designation of YF-96A. Budget politics and other considerations, however, led the Air Force to change the designation back to F-84F.

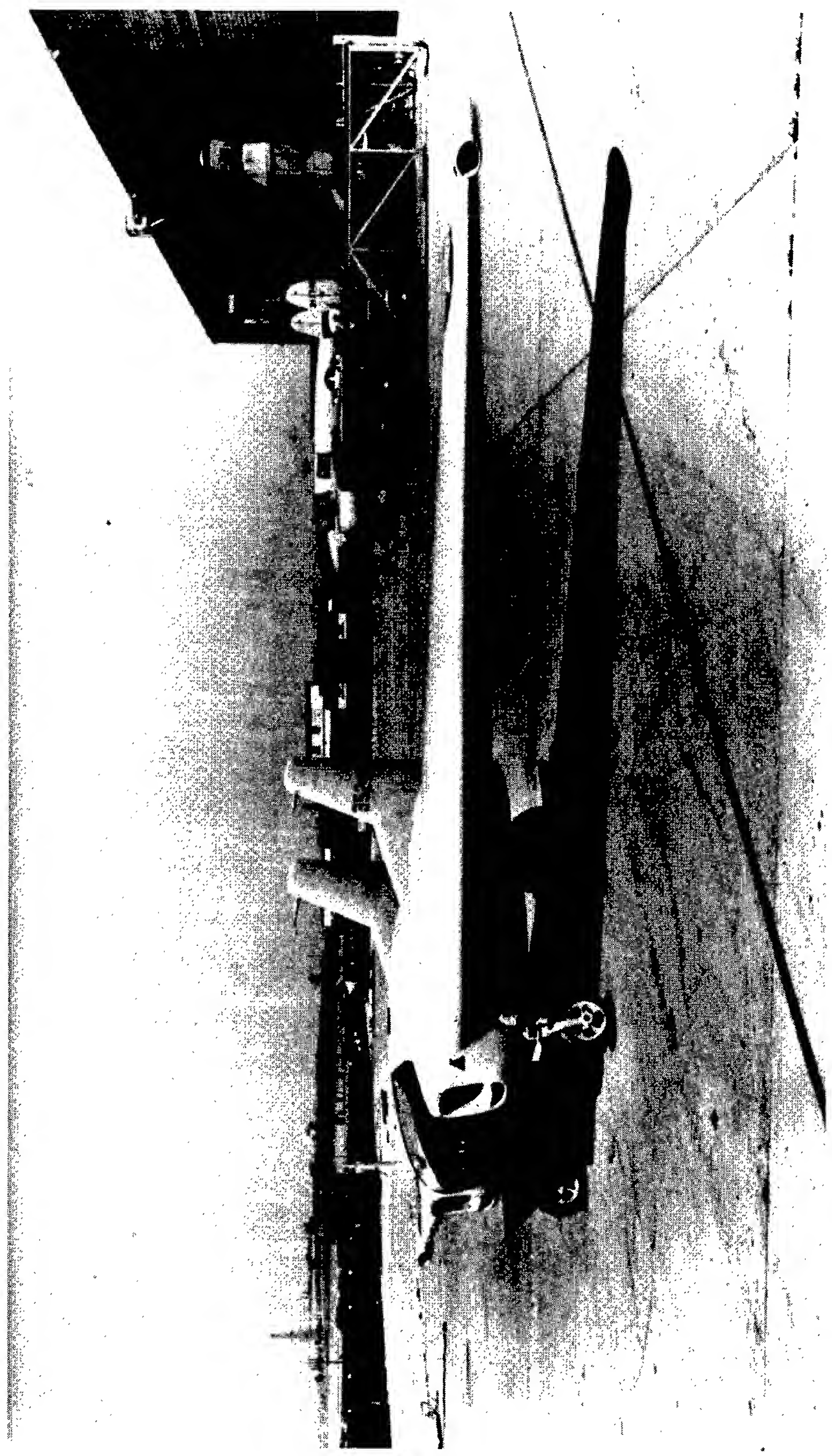


Photo 2.7—Northrop XP-79B Jet Flying-Wing Fighter. The prototype first flew in September 1945.

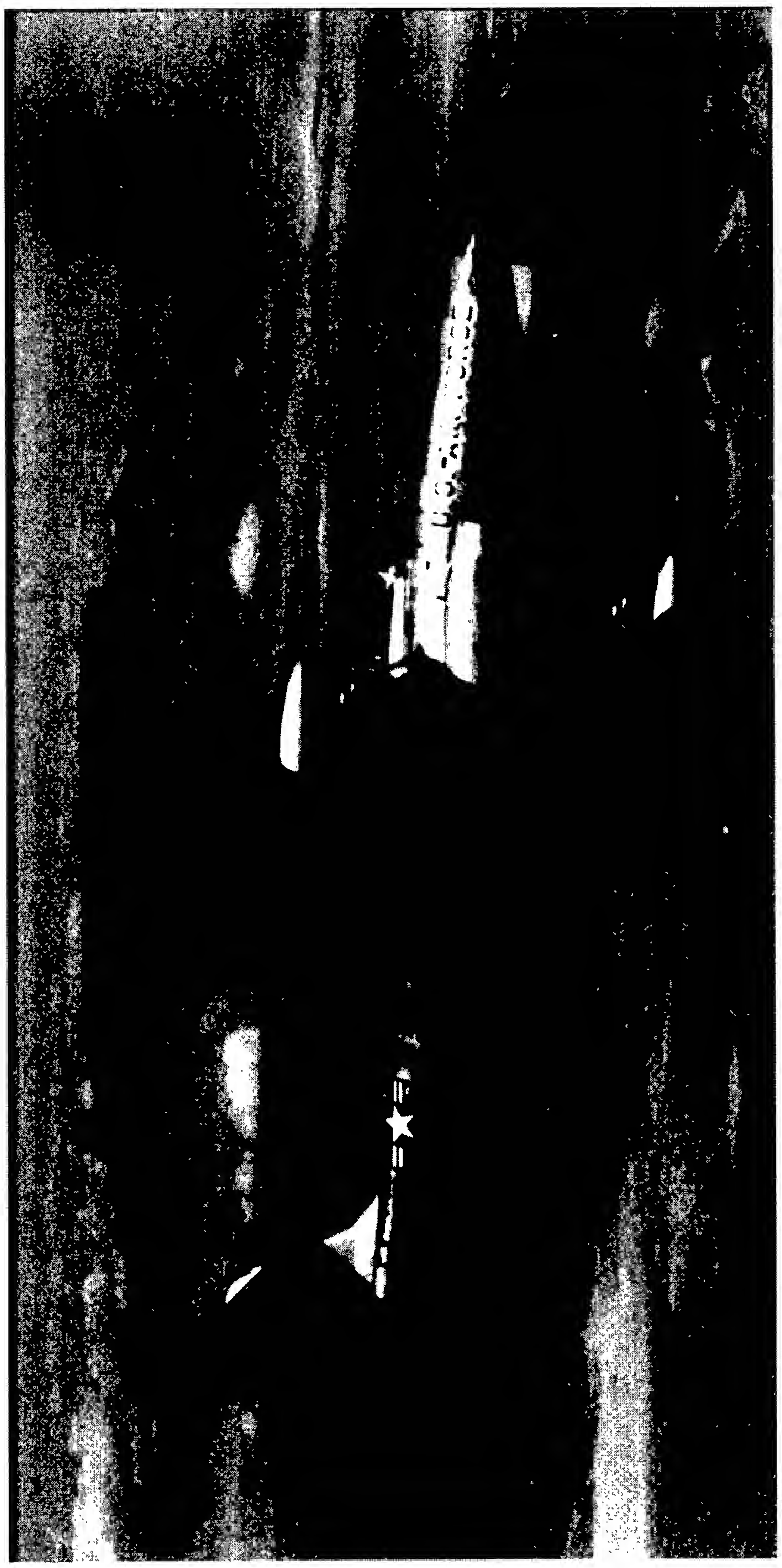


Photo 2.8—The Northrop F-89J Scorpion, as shown here, carried unguided AIR-2A Genie air-to-air missiles armed with nuclear warheads. First flown in August 1948, the F-89 was the last Northrop combat aircraft procured by the Air Force before the stealth era.

successful, it experienced numerous initial developmental problems and was not ready for operational use during the Korean conflict.[25]

With the low-thrust, high-fuel-consumption jet engines of the 1940s improving only slowly, development of a long-range jet-fighter escort for protection of strategic bombers remained a major technological challenge of the era. In mid-1946, after testing had shown that the composite prop and jet fighter was not a viable concept,[26] the Air Force tried once again to see if industry could develop a long-range escort fighter. Since the technological risk remained high, the Air Force wisely sponsored a prototype fly-off among several contractors. Lockheed responded with its first attempt at a swept-wing fighter, the XF-90, which had evolved from its highly successful but now outdated F-80 design. North American built on its F-86 experience to derive the XF-93, particularly impressing the Air Force with its swept-wing design. Although McDonnell was achieving considerable success with its early straight-wing Navy jets, the FH-1 and FH2, the young St. Louis company hoped to break into the Air Force market because of the much larger production contracts. McDonnell won an R&D contract in late 1945 for a highly unusual "parasite" fighter, the XF-85 Goblin, which was intended to deploy from inside of the massive Convair B-36 bomber to provide fighter escort protection over enemy territory. The XF-85 was McDonnell's first swept-wing fighter, and thus contributed to the company's engineering and design capabilities. But McDonnell wanted participation in a more mainstream Air Force effort and succeeded in winning a prototype contract for its XF-88 design to compete against the Lockheed and North American entries for the long-range fighter escort.[27]

Flight test results in 1950 led the Air Force to conclude that all three designs were inadequate. But the tests also demonstrated that the McDonnell XF-88 possessed considerable potential, and the Air Force encouraged further development. Although interrupted by the Korean War, development later continued and eventually resulted in a successful new design, the F-101 Voodoo penetration escort fighter.

[25] Republic developed two interesting fighter technology-demonstration prototypes related to the F-84, which were flight tested in the late 1940s and early 1950s. The innovative XF-91 Thunderceptor, which first flew in May 1949 ,used an unusual variable incidence wing and V-tail configuration. The XF-91 also employed rocket assist. The XF-84H was used in the mid-1950s to investigate turboprop propulsion for fighters as a means of providing greater short takeoff and landing capability and enhancing load-carrying capacity. At the same time, Lockheed and Convair were attempting to develop tail-sitting turboprop fighters for the Navy that had vertical takeoff and landing capability. These two fighters, the Lockheed XFV-1 and the Convair XFY-1, both proved unsatisfactory, as did the Republic XF-84H.

[26]The composite fighter concept attempted to solve the problem by providing a piston engine for fuel-efficient cruise to the target, and a jet for combat maneuvering. However, the aerodynamic compromises and high weight of such aircraft made them poor performers.

[27]See Johnson (1960), p. 67.

Photo 2.9—The innovative Republic XF-91 Thunderceptor, which first flew in May 1949, was conceived as a high-altitude interceptor. In late 1951, the Air Force canceled further development of the XF-91 in favor of the Convair F-102.

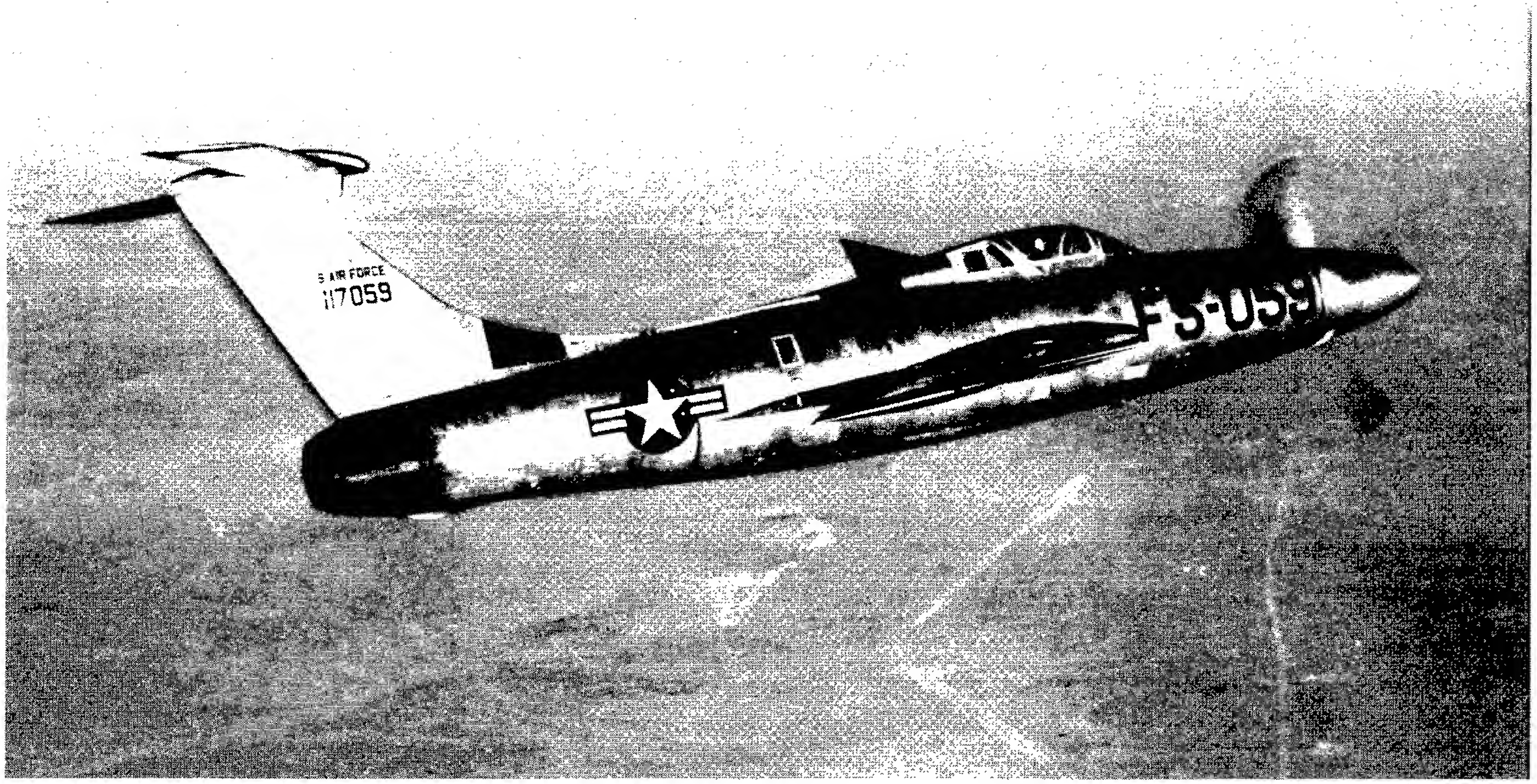
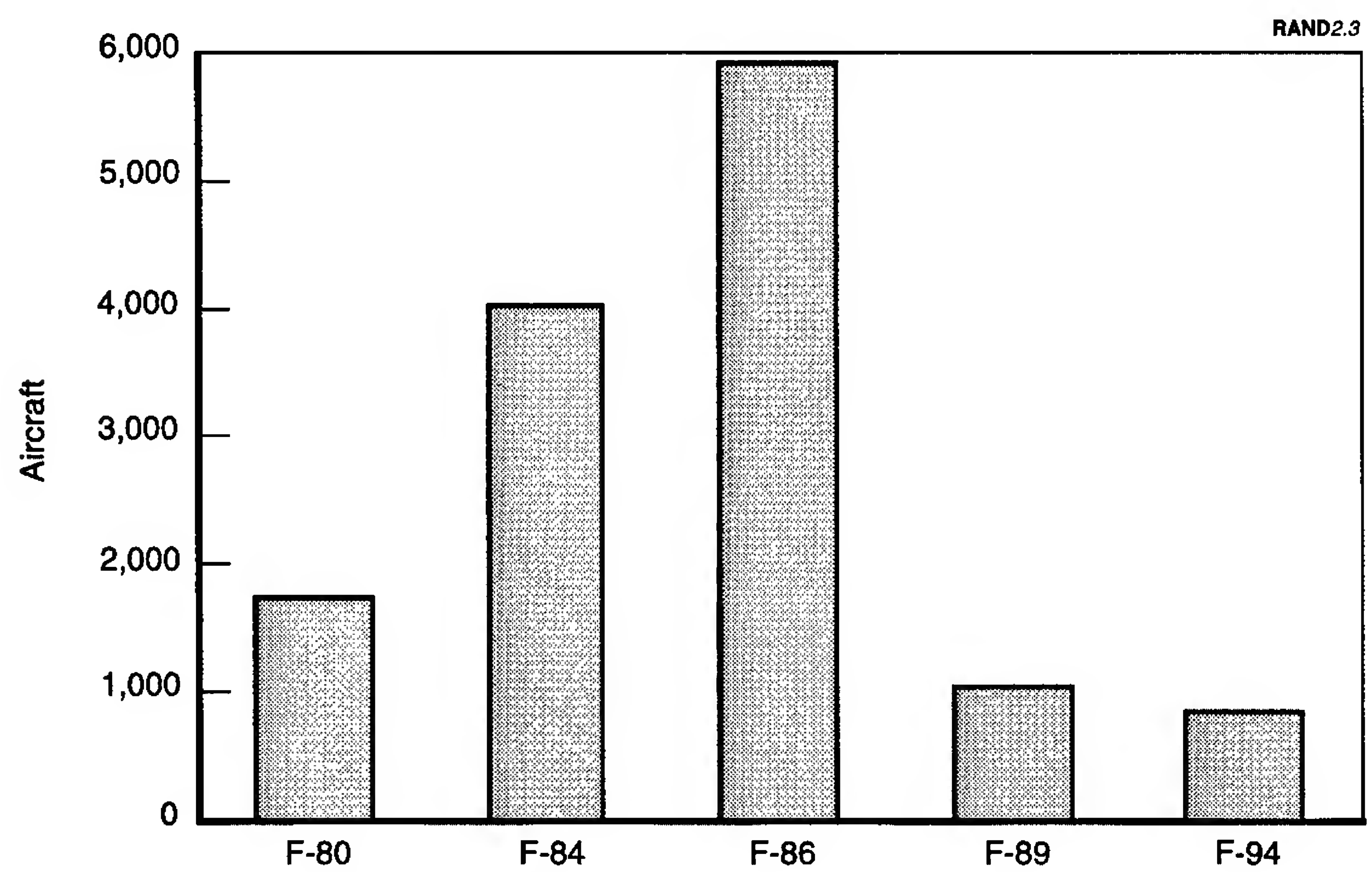


Photo 2.10—The Republic XF-84H investigated the use of turboprops to enhance short-takeoff capabilities for fighter bombers. First flight took place July 10, 1955.

Photo 2.11—The turboprop-powered Lockheed XFV-1, pictured here, competed in 1954 and 1955 with the Convair XFY-1 to provide a tail-sitting vertical-takeoff fighter for the Navy. Both prototypes proved unsuccessful.

At the end of the 1940s, the Air Force also supported development of two new interim all-weather fighter interceptors with radars and extensive electronics systems because of concern about schedule slippage in the Northrop F-89 program.[28] These two new fighters—the Lockheed F-94 and the North American F-86D—were directly derived from successful existing types. The F-94 was originally very close to the two-seat version of the F-80, but later versions—especially the F-94C—changed considerably.[29] The F-86D actually represented a practically all-new aircraft, retaining only about 25 percent commonality with standard versions of the F-86. In overall appearance and aeronautical configuration, however, the two new fighters remained generally similar to the earlier designs on which they were based.

Many observers view the F-86 as the best operational U.S. fighter of the first postwar decade. As shown in Figure 2.3, the Air Force procured more F-86s than any other contemporary fighter. Thus, North American can be credited with developing what many military experts consider as both the best U.S. fighter of World War II—the P-51D Mustang—and the best first-generation jet fighter.



SOURCE: Knaack, 1978.

Figure 2.3—Air Force Procurement of First-Generation Jet Fighters

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[28]Knaack (1978), p. 69.

[29]Because it differed so dramatically from earlier models, the Air Force initially designated the F-94C as a new fighter, the F-97.

In this case, system-specific experience seemed to transcend radical changes in technology. The Air Force also bought large numbers of F-84s. This suggests that Republic, the developer of the most-produced fighter of World War II—the P-47 Thunderbolt—had also adjusted well to the jet era. Lockheed, building on the success of its P-38 Lightning, developed the F-80 as the first successful operational jet, followed by the F-94. Northrop continued in the niche market it had carved out with the P-61 Black Widow through development of the F-89. Other earlier leaders in Air Force fighter R&D, such as Curtiss, Boeing, and Bell, which had fallen out of the fighter market during World War II, did not make the transition to jet fighters.

Similarly, the leading Navy fighter developers of World War II carried on through the first generation of Navy fighters. The Navy's lower priority for jet-fighter development, however, may have contributed to the entrance of at least one significant new player—McDonnell Aircraft Corporation.

The Navy Pursues a More Conservative Approach

Unlike the Air Force, the Navy remained skeptical about jet fighters even after the war ended. Believing that the special problems of operating first-generation jets from aircraft carriers remained valid, the Navy pursued development of composite prop and jet fighters, such as the Ryan XF2R Fireball and Curtiss XF15C until well after the war ended.[30] Furthermore, it continued to invest heavily in prop-powered aircraft developed late in World War II, such as the Douglas A-1 attack aircraft and the Lockheed Neptune patrol aircraft.[31] With a few exceptions, the Navy approach to jet-fighter R&D immediately after the war generally focused on more conservative designs and approaches than the Air Force. Even after it had developed successful first-generation jet fighters, the Navy initially procured them in only relatively small numbers.

One of the major shortcomings of early Navy jet-fighter R&D was the failure to develop a high-performance swept-wing design. While the Air Force had accepted North American's radical swept-wing F-86 modification proposal of the basic FJ-1 Navy design in 1945 and thereby achieved a dramatic increase in

[30]The major technological challenge confronting the developers of Navy jet fighters revolved around the basic problem of successfully launching jet fighters powered by low-thrust first-generation engines from relatively short aircraft carrier decks. This problem was solved by larger decks, more powerful engines, and steam catapults.

[31]The Douglas A-1 turned out to be an extremely effective attack aircraft—at least in lower intensity conflicts—serving in combat well into the 1970s during the Vietnam War. The Lockheed Neptune also had a long and successful career, and was sold to many foreign customers.

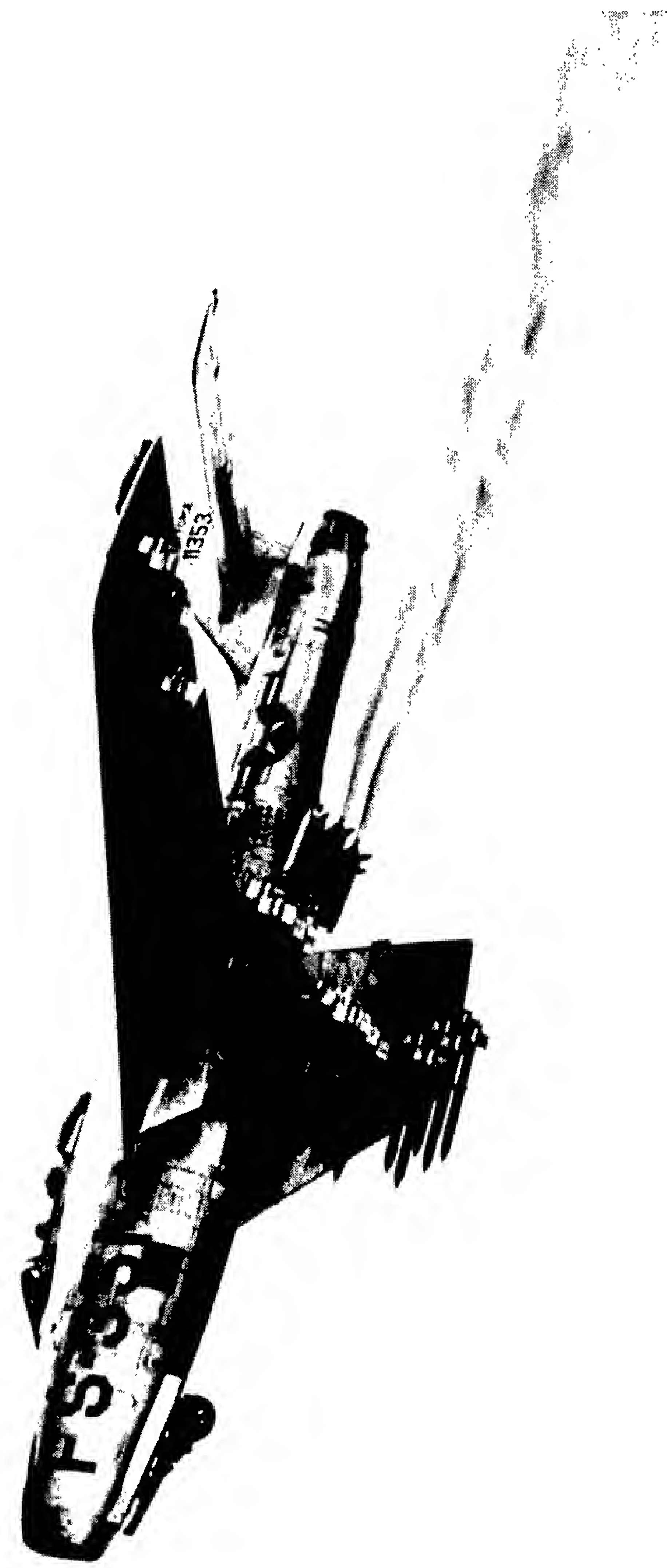

Photo 2.12—The Republic F-84F Thunderstreak was a greatly modified swept-wing version of the F-84E that was widely procured by European allies in the 1950s, as well as by the U.S. Air Force.

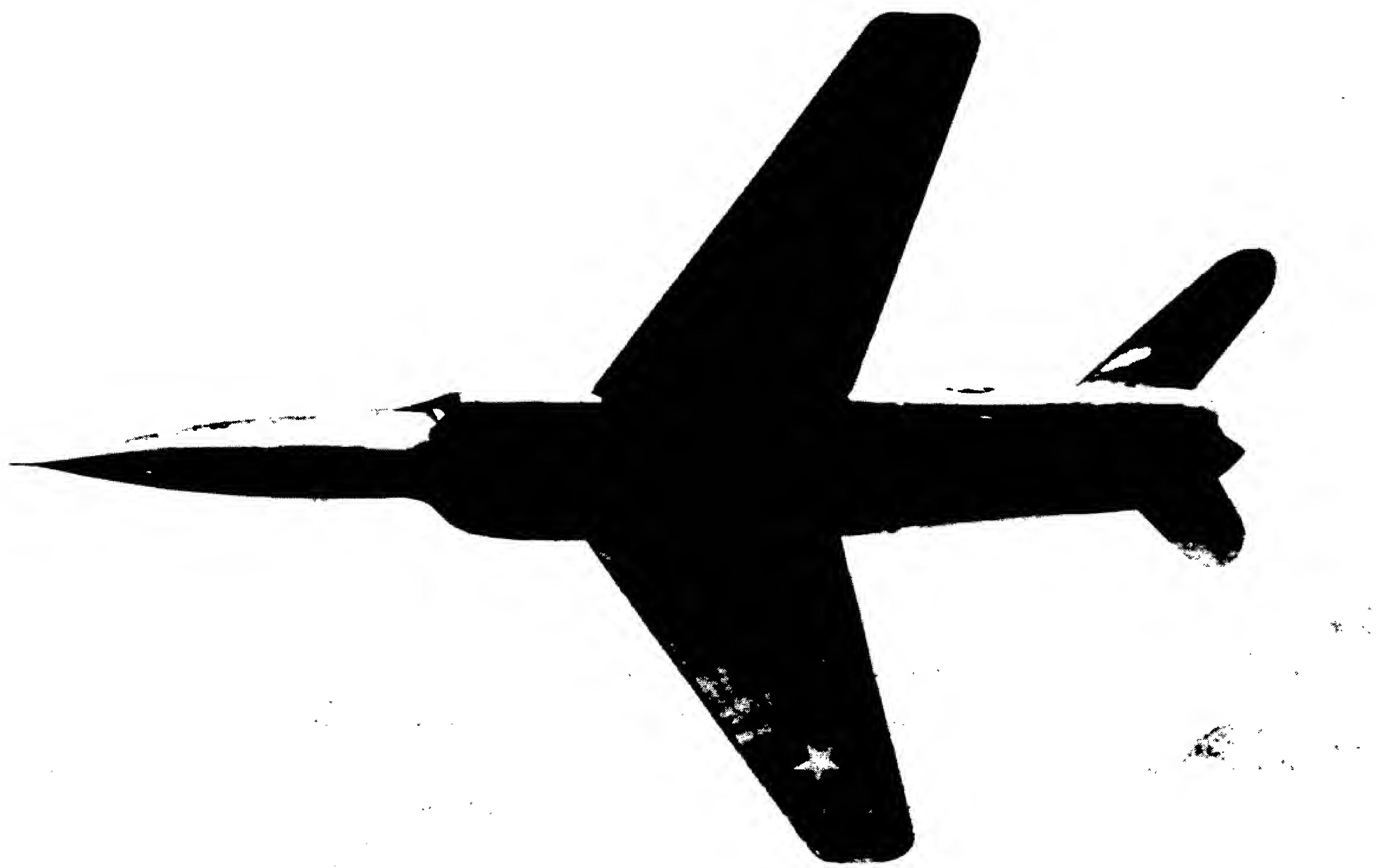

Photo 2.13—The Lockheed XF-90 long-range fighter prototype competed against the McDonnell XF-88 and North American XF-93 during flight tests undertaken in 1950. Although the Air Force considered all three to be inadequate, McDonnell was encouraged to develop the XF-88 further, which eventually evolved into the F-101 Voodoo.

speed performance, the Navy stayed with the straight-wing FJ-1. Meanwhile, McDonnell successfully scaled up its straight-wing FH-1 Phantom carrier jet fighter, which it had developed during World War II, into its F2H Banshee. With a first flight in 1947, the Banshee became the standard Navy fighter-attack aircraft by the beginning of the 1950s. While a sturdy workhorse for the attack mission, the Banshee remained relatively slow with uninspired performance.

Finally accepting that jets were here to stay, the Navy turned to Grumman, its most trusted fighter developer of the war, to develop a jet. Grumman began work on its first jet-fighter design in April 1946. This development effort resulted in the robust but conservative straight-wing F9F Panther, which became the backbone of the Navy fighter force through the Korean War. Douglas, another long-time Navy developer, weighed in with the Navy's first jet night fighter, the F3D Skynight. First flying in March 1948, the F3D was also a relatively conventional straight-wing design.

The Navy's initial attempts to support more radical design proposals seemed to confirm the wisdom of its conservative approach. They may also suggest the special difficulties and unique conditions that confronted developers of a first-generation jet fighter equipped with relatively low-thrust engines that had to operate from the confined and difficult environment of an aircraft carrier deck. In the wake of its ill-starred F6U-1 Pirate jet-fighter program, and as an attempt to counter McDonnell's initial success with conservative straight-wing Navy jet designs, Vought turned to German data for more radical and innovative concepts that might provide dramatic performance improvements. Inspired by research data on delta-wing planforms from the German Arado company,[32] Vought's highly unusual tailless F7U-1 Cutlass design was authorized in June 1946 for R&D. The resulting aircraft proved to be largely unsatisfactory in performance. In response, Vought drastically redesigned the aircraft while keeping the same designation and general configuration. First flown in December 1951, the redesigned F7U-3 Cutlass proved modestly successful in performance, although about one-quarter of the operational aircraft were eventually lost in accidents.[33]

In late 1948, Douglas also won a contract for an unconventional new Navy fighter whose design drew heavily on German delta-wing research data. The resulting manta-shaped F4D Skyray, which first flew in January 1951, experi-

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[32]Arado was the developer of the Ar 234, the only dedicated twin-engine German jet bomber that saw operational service during the war. Four-engine versions of the jet bomber were on the drawing boards when the war ended.

[33]Green and Swanborough (1994), p. 588.

Photo 2.14—A variant of the Vought F7U-1 Cutlass. First flying in 1948, this highly unorthodox fighter design experienced numerous developmental problems. Vought eventually redesigned the fighter as the F7U-3 Cutlass.

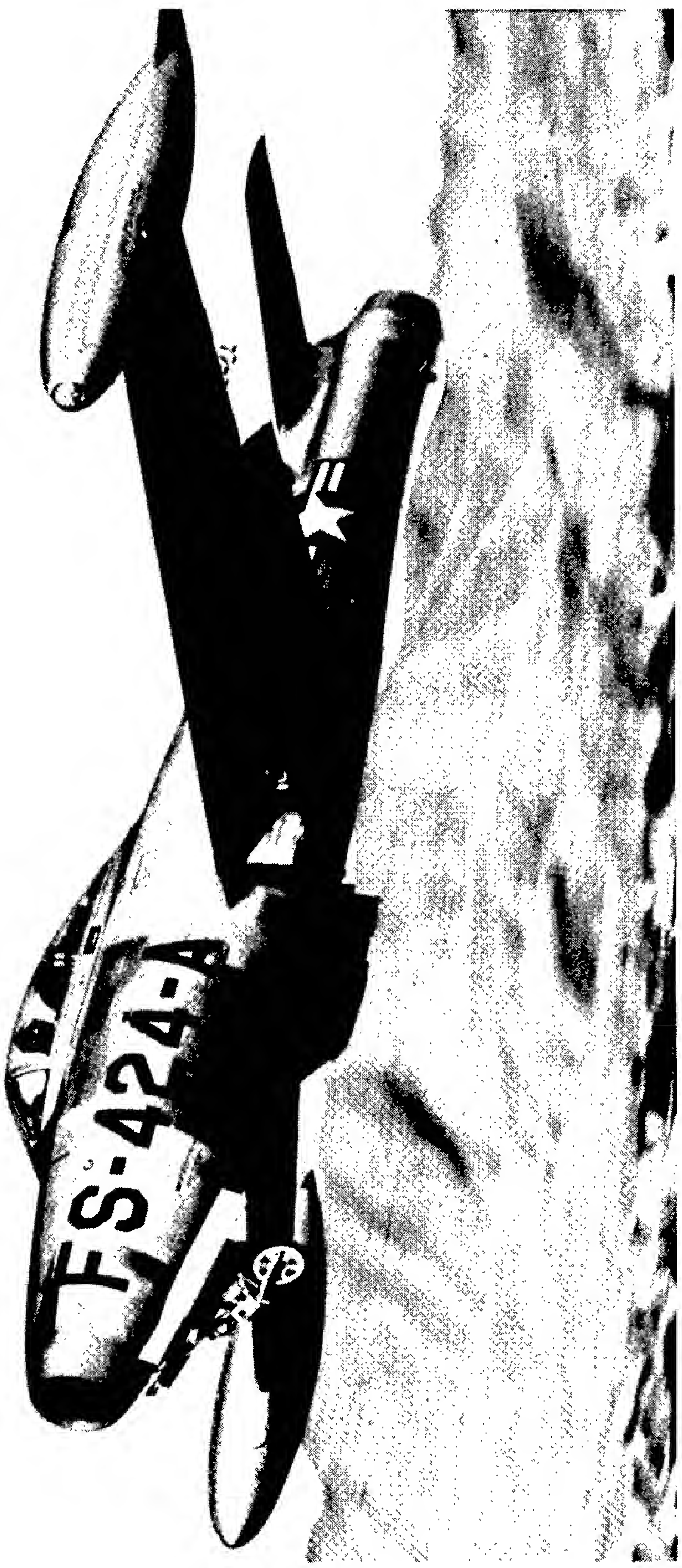

Photo 2.15—The Republic F-84E/G Thunderjet series was widely used in Korea for ground-attack operations but lacked the agility necessary for successful air-to-air combat against North Korean MiG 15s.

enced numerous discouraging developmental problems.[34] Later developments of this aircraft proved more successful, but these improved versions were not available at the time of the Korean conflict.

Even McDonnell's first attempts at a high-performance carrier fighter initially experienced significant difficulties. Touting its experience with the XF-85 and XF-88 swept-wing Air Force fighter designs, McDonnell won a contract in September 1949 to develop the F3H Demon, the Navy's first carrier-based fighter designed from its inception with swept wings. Achieving first flight in August 1951, this fighter also initially experienced severe difficulties that significantly delayed the R&D program, although most of them were related to engine R&D problems.

As a result of its conservative approach and the developmental problems its contractors encountered, the Navy was not able to deploy a fully satisfactory swept-wing jet fighter until the very end of the Korean War. Air Force aircraft benefited from an early emphasis on swept-wing technology. Soon after the Air Force introduced the swept-wing North American F-86A fighter into combat in Korea in late 1950 to counter the Soviet-designed swept-wing MiG 15, the U.S. fighter rapidly won air superiority for American forces.[35] Although the Russian-built fighter significantly outperformed the straight-wing Republic F-84E in air-to-air combat, the Thunderjet nonetheless became one of the most robust and effective ground-attack fighters of the war. Furthermore, in full recognition of the importance of swept wings, the Air Force had authorized development of the swept-wing F-84F well before the outbreak of the war, but R&D difficulties prevented operational deployment until after fighting ceased in Korea. Delay of the F-84F caused few problems, however, because the F-86A and later variants of the Sabre continued to dominate the air war throughout the Korean conflict, achieving a 10:1 kill ratio against enemy aircraft.

The Navy, however, entered the Korean War with no operational swept-wing carrier-based fighters. Like the Air Force F-84E, its existing straight-wing fighters could not match the speed of the MiG 15. In hopes of quickly remedying this shortcoming, the Navy authorized two simultaneous "quick-fix" programs in March 1951. One called for the addition of swept wings to the sturdy Grumman F9F-2/5 Panther, and the other envisioned development of a navalized version of the highly successful Air Force F-86. Both programs, however, turned out to have been overly optimistic in their anticipation of the relative ease of carrying out these modifications.

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[34]Both the F4D and the F7U-3 were tailless designs developed at a time when the aerodynamics of this configuration were not yet fully understood.

[35]Knaack (1978), p. 54. The U.S. ability to maintain air superiority over North Korean forces was also attributable to the superior training and skill levels of U.S. pilots.

North American quickly modified the F-86E for carrier operations by installing folding wings and carrier-capable landing gear and making a few other minor alterations. These changes, however, added 1,000 lbs. of extra weight, reducing the newly designated FJ-2 Fury to an unsatisfactory level of performance. These problems were not fully resolved until the installation of a more powerful engine and other modifications completed near the end of the war. The Navy also approved development of a much-higher-performance version, the FJ-4, during the war. The FJ-4 was so dramatically different from early versions that it amounted to an all-new aircraft type. Although the FJ-4 performed well, it entered operational service too late for the Korean conflict. Its performance was roughly equivalent to the final USAF production version of the Sabre, the F-86H, which had first flown in May 1953, about a year and a half before the FJ-4.[36]

Indeed, the Navy's first successful carrier-based swept-wing fighter ended up being a modification of its successful straight-wing Grumman F9F-2/5. Authorized for development in March 1951, the swept-wing F9F-6/8 Cougar was nearly identical to the Panther except for the wing. Although delivery of the new fighter to operational units began by the end of 1952, the early version of the Cougar did not perform up to expectations. A much more radically modified version, the F9F-8, began development almost immediately, first flying in January 1954. This much-improved version, of course, was too late to see action in Korea.

Thus, throughout most of the Korean conflict, Navy fighters were outclassed by both the enemy MiG 15 and the Air Force F-86. The only operational swept-wing carrier fighter used in significant numbers by the Navy was a direct derivative of the USAF Sabre design. By the end of the war, the Navy was determined never to be caught in a similar position again. Whereas Grumman appeared to have transitioned reasonably well from its leadership in Navy prop fighters to first-generation jet fighters, Vought seemed to have faltered by attempting development of more unconventional designs. Two new players in Navy fighters—McDonnell and Douglas—had performed reasonably well with their initial efforts, but experienced trouble with later designs.

But all contractors—both Navy and Air Force—would soon be confronted with a more level playing field as they attempted to conquer the next and perhaps greatest technology challenge to date: supersonic flight.

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[36]Jones (1977), p. 278.

Chapter Three

THE SUPERSONIC REVOLUTION

EVER FASTER AND HIGHER: JET-FIGHTER R&D TRENDS IN THE 1950s

The increases in speed and altitude capabilities of fighters and bombers, as well as weight and cost, which had begun with the introduction of jet engines in the 1940s, escalated even more dramatically during the 1950s. This was due both to rapid advances in technology, which permitted development of supersonic fighters, and to the mission performance goals required by the new prominence of nuclear weapons in U.S. national security strategy.

Throughout most of the 1950s, President Eisenhower's heavy reliance on a deterrent policy of "massive retaliation" led to an emphasis on specialized strategic and tactical nuclear missions for the armed forces. The Air Force and—to a somewhat lesser extent—the Navy tended to seek fighters and bombers designed to operate in a theater or strategic nuclear environment, in support of offensive nuclear operations or defending against enemy strategic nuclear attack. As the key platform for delivering strategic nuclear weapons, bombers enjoyed a high priority for R&D and procurement in defense budgets of the period.[1]

Doctrine thus dictated a set of missions that, along with the rapidly advancing state of jet aircraft engine and airframe development during this pioneering period, determined design requirements and performance goals. These tended to stress speed, ceiling, payload, range, and penetration capability over maneuverability and sustained sortie rates.

By the early 1950s, large advances in jet turbine engine power and efficiency, the advent of the afterburner, and resolution of the basic aerodynamic design problems posed by very-high-speed flight led to an explosion in aircraft speed and altitude capabilities. Compared to first-generation jets, second- and third-generation fighters and bombers became ever faster, higher-flying, heavier, and

[1]See Coulam (1977), p. 47, and White (1974), pp. 67–68.

larger to meet the requirements of strategic doctrine and the nuclear battlefield, as shown in Tables 3.1 and 3.2.

First-generation jet fighters, such as the Lockheed F-80, boasted performance characteristics only modestly superior to the most advanced piston-engine aircraft of the era. For example, the top speed of early versions of the F-80 was only a little over 100 mph faster than the most advanced versions of the piston-engine North American P-51. In contrast, the 19,460-lb. F-102A interceptor performed in early testing at a maximum speed in excess of Mach 1 with a combat ceiling over 50,000 feet, while its planned successor, the 23,646-lb. F-106A, approached Mach 2 and attained similar altitudes.[2] By the late 1950s, the Air Force was examining proposed interceptors, such as the XF-108 and the 60,000-lb. YF-12A, designed to engage in combat at speeds in excess of Mach 3 and altitudes above 75,000 feet.[3] Fighter-bombers developed during this era, such as

Table 3.1

Selected U.S. Air Force Fighters, 1947–1962

Fighter	First Flight[a]	Cost[b] ($000)	Empty Weight (lbs.)	Max. Speed (mph)	Ceiling (feet)
F-80C	1944	584	8,240	600	42,750
F-84G	1946	1,334	11,095	622	40,500
F-86F	1947	1,181	10,950	678	45,000
F-86D	1949	1,931	13,498	692	49,600
F-89D	1948	4,501	21,000	610	48,000
F-94C	1949	3,003	12,708	600	51,400
F-100D	1953	4,201	21,000	864	47,700
F-101B	1954	9,234	28,000	1,100	50,300
F-102A	1953	6,761	19,460	825	51,800
F-104C	1954	9,797	14,082	1,450	58,000
F-105D	1955	10,508	27,500	1,480	50,000
F-106A	1956	23,859	23,646	1,525	52,000
F-4C	1958	8,803	28,540	1,500	55,400
F-111A	1964	39,922	46,172	1,450	57,900
YF-12[c]	1962	66,000–81,000	60,000	2,200	84,000

SOURCES: Knaack, 1978.

[a]First-flight year is for the first prototype of each basic aircraft type, except for the F-86D.

[b]Unit flyaway costs, estimated for a 100-aircraft production run, based on 1993 dollars.

[c]Not deployed operationally.

[2]Johnson (1960), p.29.

[3]Knaack (1978), pp. 330–333.

Table 3.2

Selected U.S. Air Force Jet Bombers in the 1950s and 1960s

	Bomber	First Flight[a]	Takeoff Weight (000 lbs.)	Maximum Speed (knots)	Combat Ceiling (feet)
Medium	B-45A	1947	92	496	32,800
	B-47A	1947	157	521	44,300
	B-57B	1953	57	520	45,100
	B-66B	1954	83	548	38,900
	B-58A	1956	163	1,147	63,000
Heavy	B-36A	1946	311	435	38,800
	B-52B	1952	420	546	46,600
	XB-70A	1964	521	1,721	75,200

SOURCE: Knaack, 1988.

[a]First-flight year is for the first prototype of each basic aircraft type.

the F-100D, F-105, F-107, and F-111, might best be characterized as very-high-speed, deep-penetration medium nuclear bombers.

The technological challenges supersonic flight posed in the areas of aerodynamics, materials, and propulsion were daunting and in many respects called for far more radical changes than had been dictated by the transition from fast prop fighters to first-generation jets. As contractors began their quest to meet service requirements for the ultimate Mach-3 fighters and bombers, a wide variety of demanding design and other technical problems had to be addressed. These included such issues as dramatic new wing shapes and cross sections, novel fuselage-shaping requirements to solve the problem of transonic drag, variable-geometry air inlets, variable-geometry and variable-incidence wings, engine afterburners, manufacturing with titanium and other exotic materials, and a myriad of other design and technological issues. These challenges contributed dramatically to the escalation in cost, weight, and complexity of fighters and bombers witnessed in the 1950s.

In addition, the weapon system requirements for the key missions of deep-penetration nuclear and conventional interdiction and interception of enemy nuclear bombers increasingly called for the development and integration of advanced fighter avionics for all-weather, day-or-night navigation, target acquisition, weapon delivery, and defensive countermeasures deep in hostile territory. Interceptors in the 1950s were intended to be marvels of push-button warfare. The pilot of the F-106A, planned by the Air Force to be the "ultimate interceptor" of the era, was intended to serve only as a monitor of the sophisticated electronic systems that would automatically fly the aircraft and deliver the MB-1 nuclear-tipped air-to-air rocket against enemy bombers. Development and integration of such systems presented U.S. industry with unprecedented technological challenges.

Although R&D and procurement costs rose significantly and expected operational capabilities were often not met, the American aerospace industry nonetheless can justifiably claim to have successfully achieved an unprecedented level of technological advancement and accomplishment during this period. At the beginning of the 1950s, the new and daunting technical challenges that the development of supersonic fighters and bombers equipped with advanced electronic subsystems posed helped reduce the relative advantage of experience that the leading fighter developers possessed and once again raised the importance of unique firm-specific capabilities. Thus, the new technological demands of supersonic flight and weapon system development helped catapult relatively new entrants, such as McDonnell and Convair, to leadership in fighter development.

A company with little experience or reputation in fighter R&D—Convair—initially won the coveted award of developing the "ultimate" supersonic fighter for the Air Force.[4] Why was this task not entrusted to one of the Air Force's leading fighter developers—North American, Republic, or Lockheed? The Air Force recognized that supersonic flight represented a significant leap ahead in fighter design, configuration, and technology. Analysts of the period suggest that Convair had firm-specific capabilities in supersonic flight that other contractors did not possess. Thus, a company with relevant firm-specific capabilities could have an advantage over another company with much system-specific experience in the old technologies.

Nonetheless, the importance of system-specific experience remained central. At the beginning of the 1950s, the Air Force's leading fighter developers—and even their relative ranking—were the same as during World War II: North American, Republic, and Lockheed. All three of these companies generally excelled at supersonic fighter development during this period. Indeed, by the late 1950s, North American could be viewed as the leading contractor for the development of both Air Force fighters *and* bombers, as well as other high-Mach-number military and research vehicles. However, by the end of the decade, Convair had also joined as a leading developer of supersonic fighters

[4]As noted earlier, Consolidated Aircraft merged with Vultee Aircraft in March 1943 to become Convair. Consolidated was a leader in bombers, seaplanes, and other large aircraft. In the 1930s, Consolidated developed the most famous seaplane used extensively in World War II, the PBY Catalina. Before the war, the company also concentrated on trainers and a heavy fighter (the P-30). Although less well known than Boeing's two famous wartime bombers (B-17 and B-29), Consolidated's B-24 Liberator was built in larger numbers for U.S. and foreign armed services than any other single type of American aircraft during World War II. Vultee was not a leading prewar contractor. Before the war, Vultee developed a fighter, attack aircraft, and light bombers, which were primarily exported. Consolidated and Vultee produced some experimental fighter prototypes during the war as their only experience in fighter R&D.

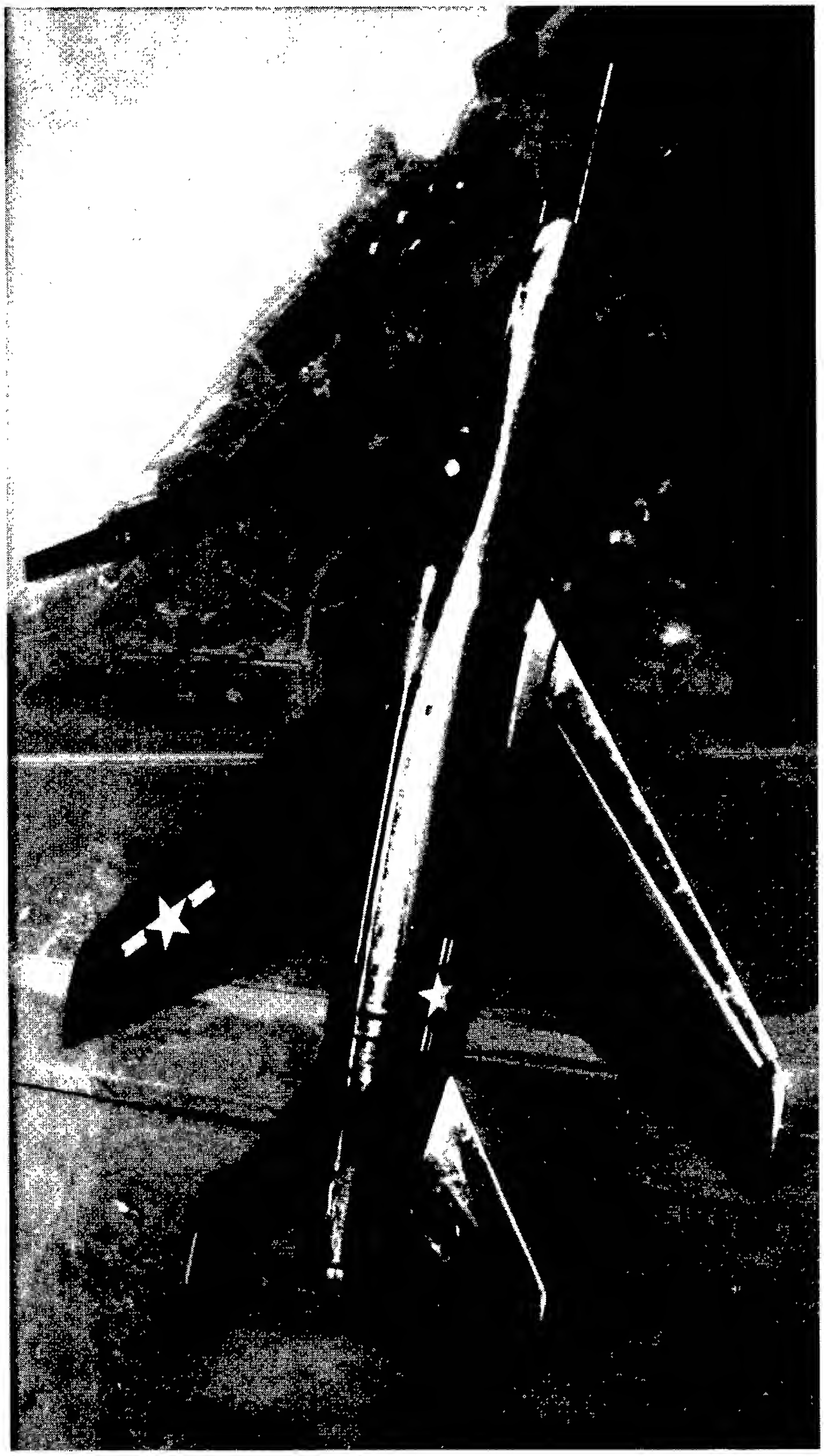

Photo 3.1—The North American F-100 Super Saber, first flown in May 1953, grew out of a company-funded project to become the first fighter to achieve sustained, level supersonic flight.

Photo 3.2—The Convair F-106A Delta Dart was the final outcome of the "Ultimate Fighter" competition of the early 1950s. Originally viewed as a modification of the Convair F-102B Delta Dagger, so many changes were required to overcome the shortcomings of the F-102B that the upgraded aircraft was awarded the new designation of F-106A.

and bombers, whereas Lockheed's position had begun to slip, at least outside of the highly secretive world of specialized reconnaissance aircraft.

In the world of naval fighter aviation, Grumman had kept its leadership position during the transition period from prop to jet fighters, but a new company—McDonnell—had also been able to establish itself. Douglas had moved forward into the new fighter technology, but Vought had stumbled. The supersonic revolution, however, thrust Vought back into a leadership role and helped launch McDonnell to a position of such prominence that the company eventually came to lead the entire U.S. industry in fighter development in the 1960s and 1970s. Grumman, meanwhile, seriously stumbled for the first time since the earlier technology revolution of the mid-1930s, when Brewster beat its design for the Navy's first monoplane carrier fighter.

The next two sections survey the development of these trends in more detail for Air Force and Navy fighters. The last section reviews the overall trends for the entire period of jet-fighter development from the mid-1940s to the beginning of the 1960s.

DEVELOPMENT OF AIR FORCE SUPERSONIC FIGHTERS

In the early 1940s, an enormous amount of technical uncertainty surrounded the concept of supersonic flight. Some observers even doubted the practical feasibility of developing a manned aircraft that could fly faster than the speed of sound for sustained periods. Much uncertainty existed over whether jet turbine engines could ever provide enough thrust to achieve supersonic flight, or whether rocket power would have to be employed. Initially, the Air Force R&D establishment at Wright Field, with the assistance of NACA, took the lead in assessing and overcoming these uncertainties.[5]

During World War II, U.S. contractors were swamped with production and R&D work directly supporting the war effort. They did not have the incentive, the available facilities, or the capabilities to investigate the problems of supersonic flight. However, beginning in 1943, the Air Force pushed for development of a rocket test vehicle to explore manned supersonic flight.[6] In 1944, the Navy rejected this approach as too risky, arguing that such an experimental vehicle should be jet powered. The Air Force, with support from NACA, decided to proceed without the Navy. The leading Air Force contractors, however, remained largely uninterested in such a visionary project because of their huge wartime

[5]Early attempts to develop supersonic planes are well documented in Perry (1965).

[6]Indeed, as early as 1941, the Air Force asked Douglas to look into the problems of supersonic flight in the Mach 1 regime.

workloads. Eventually, however, Bell agreed to help develop and manufacture the experimental aircraft—the famous X-1—based on design studies and specifications developed largely by the Air Force and NACA.[7] Late in the war, the Air Force and NACA also asked Douglas to examine designs for a Mach-2 manned experimental aircraft, later designated the X-3.[8]

In October 1947, the Bell X-1 became the first manned aircraft to break the sound barrier. The Air Force and NACA used the X-1 and later variants for an extensive series of highly successful supersonic flight tests that were entirely for collecting data on the aerodynamics of transonic and supersonic flight. These data contributed enormously to expanding the knowledge base necessary to develop supersonic fighters.

Meanwhile, the Navy, also teamed with NACA, moved ahead with its much more conservative program for the development of the jet-powered Douglas D-558-1 Skystreak. This aircraft, however, was never able to break the sound barrier because of the shortcomings of first-generation jet engines. A heavily modified composite jet-rocket version, the Douglas D-558-2 Skyrocket, finally broke the sound barrier in June 1949 but still could not be used extensively as a practical research vehicle for supersonic flight. This experimental aircraft was later further modified to an all-rocket configuration similar to the Bell X-1. The modified Skyrocket did not feature many of the emerging technologies that eventually made supersonic flight practical, yet it was used to carry out a successful supersonic test program in the early 1950s.[9]

Although Bell's experimental aircraft performed its function well, the X-1 remained far from an operational fighter aircraft. The airframe design was very conventional; it did not even have swept wings. Among other operational shortcomings, it had to be carried aloft under a large aircraft and launched in the air, and the fuel limitations of its rocket engine gave it a very short period of powered flight.[10] Yet almost from the beginning of the X-1 program, visionary Air Force and industry officials began examining ways to go beyond experimental aircraft to the design and development of useful supersonic fighter and bomber design concepts. As early as 1946, the Air Force launched a major study program for investigating design approaches for high-speed jet bombers, called the first Generalized Bomber Study, or GEBO I.[11] Convair, as a major bomber developer of World War II, played a major role in this study, as did North

[7]See Guenther and Miller (1988).

[8]Francillon (1990a), p. 450.

[9]See Francillon (1990a).

[10]See Perry (1965,, pp. 25–26.

[11]Miller (1985), p. 17.

American, Boeing, and other contractors.[12] The Air Force had also issued requirements for three new fighter types in August 1945, and in response, Convair engineers began investigating large numbers of novel design concepts for a very-high-speed fighter-interceptor.

Despite its experience with the X-1, Bell remained at a disadvantage in these early design competitions for the Air Force's first operational supersonic fighter. Bell had developed only one basic operational fighter type—the P-39 Airacobra and its variants—and that fighter had major shortcomings. Bell had received the contract to build the X-1 in 1944 in large part because it was the only contractor with available facilities that had any interest in the project. Furthermore, the X-1 concept and overall design had been developed by the Air Force and NACA, not by the contractor. Perhaps most important, the basic design and straight-wing planform of the X-1 (as well as the Navy's D-558-1) were clearly not the optimal design approach for a supersonic fighter.

Yet, well into the 1950s, several unresolved aerodynamic and structural questions continued to cause considerable uncertainty about the ideal wing planform shape for a supersonic fighter. Some of the initial German test and theoretical data that led North American to adopt a swept wing for the F-86 also suggested that such a wing would be a poor choice for a supersonic fighter. Areas of major concern included the problems of supersonic drag, transonic and low-speed handling qualities, and the structural integrity of thin, radically swept wings.

Following his capture in the spring of 1945, a leading German aerodynamic engineer, Dr. Alexander Lippisch, provided the Air Force and NACA with considerable test data suggesting that a delta-wing configuration might be the best approach for supersonic fighters and bombers. Lippisch had been experimenting with tailless delta designs since the 1920s and had designed the rocket-powered Me 163 Komet fighter (although not a true delta design) that had been the first manned aircraft to exceed 700 mph. During the late stages of the war, the German engineer had produced the P-14 delta-wing fighter design intended to fly at a speed of Mach 1.85 (1,215 mph).

Convair engineers, who were deeply involved in the Air Force design competitions for new fighters and bombers, met Lippisch in 1946 at Wright Field and were greatly impressed with his theories and data. Extensive in-house studies and wind-tunnel testing seemed to confirm Lippisch's views, leading Convair engineers to adopt a delta configuration for its advanced supersonic fighter

[12]As noted earlier, Convair's B-24 heavy bomber was produced in greater numbers than any other type of military aircraft during World War II. Convair's giant B-36, first flown in 1946, became the standard USAF strategic nuclear bomber in the early postwar years.

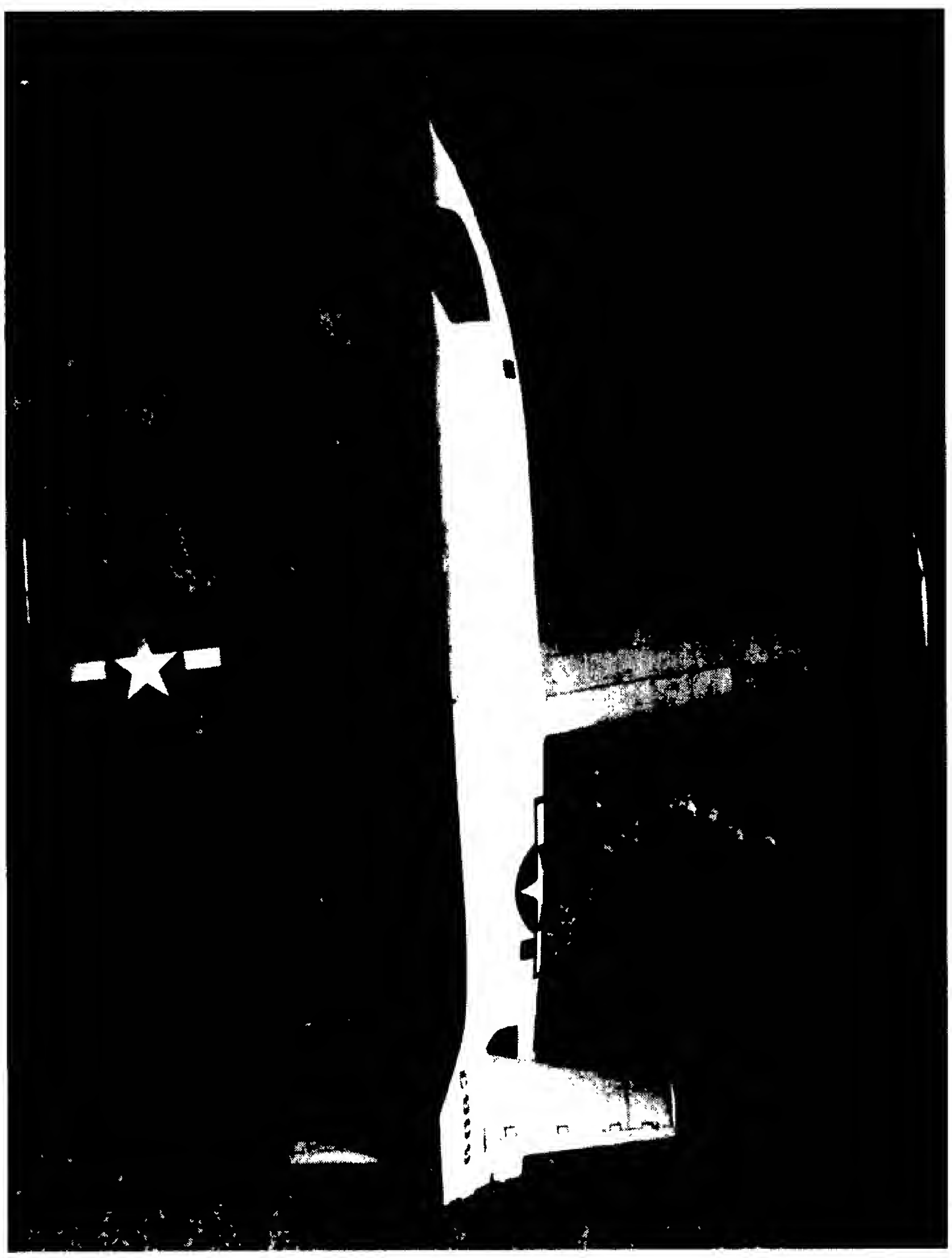

Photo 3.3—The famous Bell X-1 was developed by the Air Force and NACA to investigate supersonic flight. On October 14, 1947, an X-1 piloted by Capt. Charles "Chuck" Yeager became the first aircraft to exceed the speed of sound.

design, eventually called the XF-92, and for many of its bomber design studies. In 1948, the Air Force decided to cancel the XF-92 fighter-interceptor program because of funding shortages, shortcomings in existing propulsion systems, and continuing uncertainties about supersonic aerodynamics. The Air Force concluded that the first prototype XF-92, which had just been completed, should be used as an experimental test bed for flight testing of the delta configuration before full-scale development of a supersonic fighter was authorized.

From 1948 through the early 1950s, the Air Force, NACA, and Convair extensively flight tested the XF-92. Unfortunately, the aircraft was underpowered, and therefore only a small fraction of the flight testing was undertaken at supersonic speeds. Nonetheless, the Air Force and NACA collected considerable performance data on the delta-wing configuration at transonic speeds, most of which seemed to confirm the view that the delta planform would be optimal for a supersonic fighter.[13]

In October 1948, Convair also began working with the Navy on a fighter that could take off and land on water using water skis. The Navy was impressed with Convair's design proposals, all of which were delta-wing configurations. In January 1951, the Navy awarded Convair a contract for development of two seaborne delta-wing fighter prototypes, designated XF2Y.[14]

Given the importance attached to the new delta-wing configuration for efficient supersonic flight and Convair's extensive experience with the XF-92 delta-wing technology demonstrator and the XF2Y design, it is not surprising that Convair fared well in the USAF's first major design competition for a supersonic fighter. The Air Force had considered many of the first-generation jet fighters to be temporary stopgap aircraft that would soon be replaced by much more advanced supersonic fighters in the 1950s. After the Air Force issued its Advanced Development Objective in January 1949 and an RFP 18 months later for its "Ultimate Interceptor," the design competition among contractors became intense. North American, Republic, and Lockheed—still considered the foremost Air Force fighter developers—submitted a total of six serious design proposals. Two leading Navy developers—Vought and Douglas—also entered designs. Convair submitted one design proposal directly derived from its XF-92 experimental aircraft.[15]

In July 1951, the Air Force selected three finalists: Convair, Republic, and Lockheed. Lockheed, however, was soon eliminated. Shortly thereafter, the Air

[13]Extensive descriptions of the development and flight testing of the XF-92 can be found in Miller (1985) and Mendenhall (1983).

[14]See Mendenhall (1983), pp. 70–86.

[15]See Johnson (1960), pp. 5–10.

Force awarded the development contract to Convair for the "Ultimate Interceptor," later designated the F-102. In addition, Republic's extremely advanced design concept for a Mach-3 high-altitude (80,000 feet) interceptor, later designated the XF-103, was approved for long-term experimental development. Interestingly, both Convair's and Republic's winning designs featured delta-wing planforms, and Convair was the only contractor that had experience with a flying delta-wing jet aircraft.[16]

Recognizing the high degree of technological risk inherent in the F-102 effort, the Air Force divided the program into two stages in late 1951. The first stage would produce the F-102A as an interim, lower-capability interceptor. The F-102B would be a more advanced version that would appear at a later date as the "Ultimate Interceptor." However, the F-102A program experienced numerous serious developmental problems and delays. By 1956, the F-102B program became a separate R&D effort for a highly modified variant of the F-102. This new fighter was eventually designated the Convair F-106 Delta Dart.

Both North American and Lockheed were extremely disappointed with the outcome of the 1951 design competition. Having lost what many considered the most important fighter competition of the early 1950s, both companies feared that, without the opportunity to build up further supersonic fighter R&D experience, they were at risk of being forced out of the fighter business. Consequently, both companies continued in-house design studies and wind-tunnel testing in the hopes that the Air Force could still be convinced to support one of their proposals.

Since 1949, North American had worked on its Sabre-45 proposal, a supersonic fighter proposal directly derived from its extremely successful F-86 Sabre design. North American's design efforts also benefited from another Air Force R&D program that was providing considerable insights into supersonic aerodynamic problems. As early as 1946, the company had been selected as the prime contractor in one of the most important pioneering R&D efforts regarding supersonic flight, the Air Force X-10/SM-64 Navaho program. Unlike the much slower and more conventional Martin TM-61 Matador and Northrop SM-62 Snark cruise missile programs and the much-shorter-range Boeing Bomarc surface-to-air missile effort, this program sought to develop an unmanned intercontinental Mach-2.75 cruise missile to deliver strategic nuclear weapons over 5,000 miles against the Soviet Union. The X-10/Navaho, with an empty weight of nearly 26,000 lbs., was in the same weight class as most contemporary fighters, and thus amounted essentially to a Mach 2+ long-range fighter R&D pro-

[16]See Knaack (1978), pp. 159–160. The Air Force later selected another related Convair delta-wing design for development as its first supersonic bomber, the B-58 Hustler.

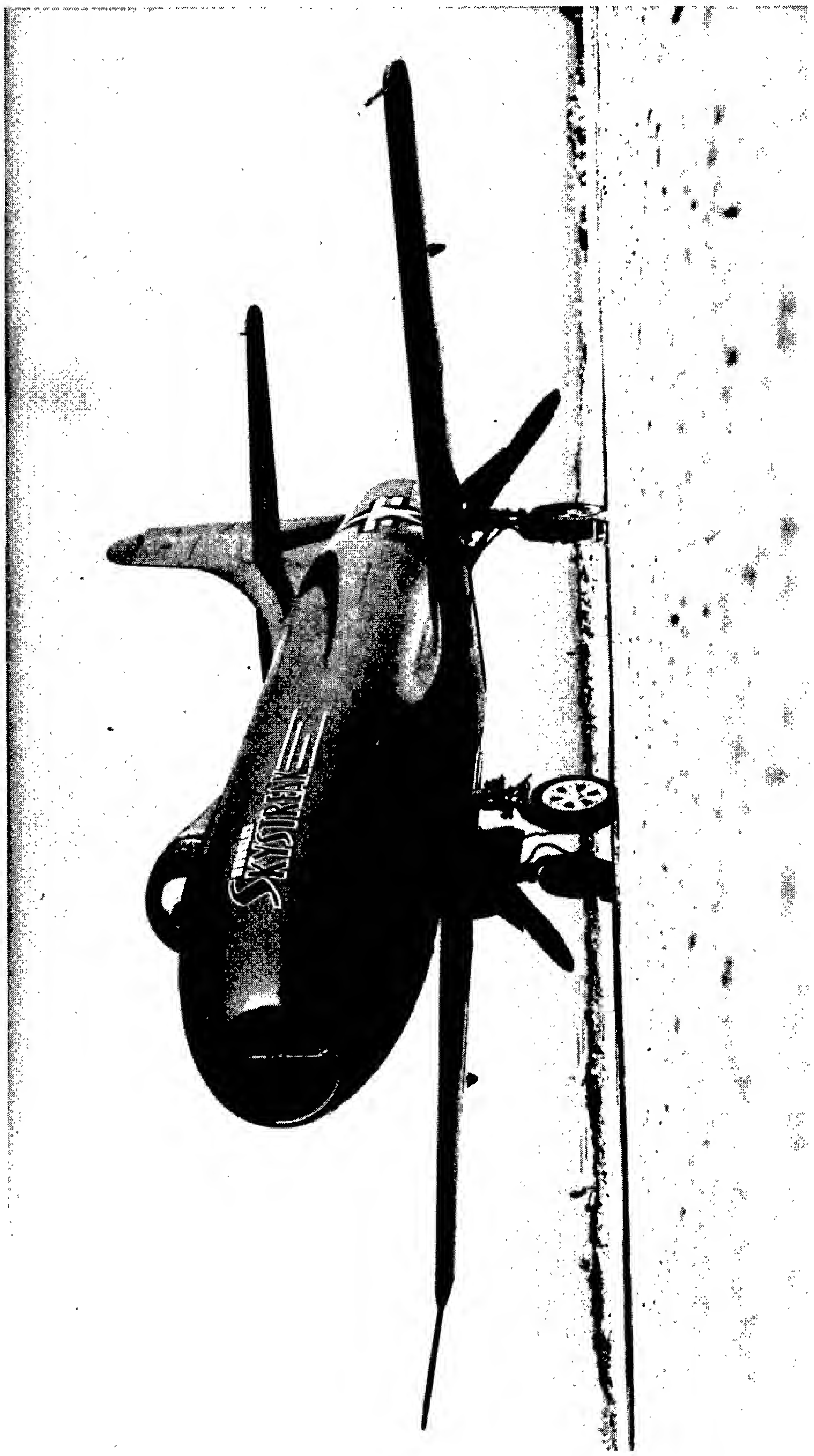

Photo 3.4—The Douglas D-558-1 Skystreak took part in an experimental Navy high-speed test program beginning in May 1947. Unlike its contemporary, the Bell X-1, the Skystreak was incapable of breaking the sound barrier.

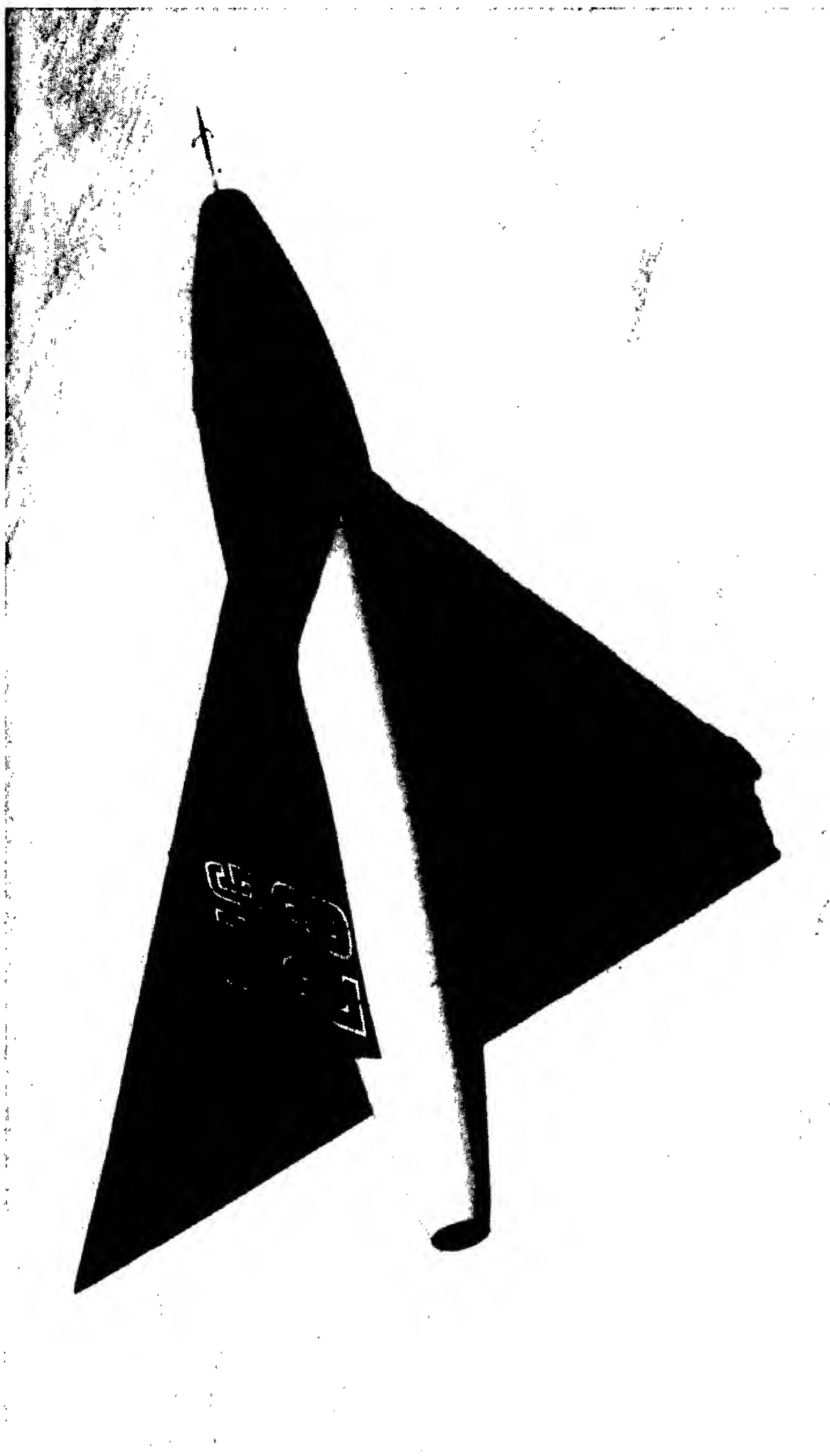

Photo 3.5—The Convair XF-92A, first flown in September 1948, contributed to the development of the supersonic delta-wing planform later used by Convair on the F-102, F-106, and B-58 Hustler bomber.

gram. Thus, in essence, North American had already been deeply involved in a design and development effort for a supersonic fighter for several years.[17]

The company's efforts finally paid off when North American was able to sell its Sabre-45 proposal to the Air Force as a less expensive supersonic day fighter to complement the all-weather F-102. The Air Force approved development of North American's F-100 Super Sabre in late 1951.[18]

Because of the ratcheting up of the Cold War in the early 1950s that was caused by the outbreak of the conflict in Korea and because of the formalization of the Massive Retaliation nuclear doctrine, there was a significant expansion in Air Force requirements for advanced supersonic fighters. Furthermore, developmental delays on the Convair F-102/106 program led the Air Force to consider supporting supplemental R&D efforts. Thus, several other contractors in addition to North American soon received contracts for advanced supersonic fighters.

In late 1951, McDonnell was finally able to benefit from the earlier success of its XF-88 prototype in the 1950 fly-off against the Lockheed XF-90 and the North American XF-93 for a long-range bomber escort. Although full development of an improved version of the XF-88 had originally been delayed because of budget restrictions and the outbreak of the Korean War, combat experience in the early stages of the conflict suggested that a new long-range escort fighter was needed. By early 1952, McDonnell had won a full-scale development contract for a significantly modified supersonic version of the XF-88—the F-101 Voodoo.

Lockheed experienced more initial difficulties than North American and McDonnell in convincing the Air Force to support one of its supersonic fighter designs. The company was extremely concerned about its future prospects in fighter R&D after the rejection of its XF-90 prototype in favor of the McDonnell XF-88 in mid-1950 and its loss to Convair and Republic in the "Ultimate Interceptor" competition. Lockheed continued developing new design proposals that drew heavily on the XF-90 and the Douglas X-3 high-speed experimental aircraft, but the Air Force turned these down in 1952.[19]

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[17]The first phase of this remarkably ambitious program aimed at developing the X-10 test vehicle intended to investigate supersonic cruise aerodynamics. North American engaged in general design studies in the late 1940s and launched the specific X-10 design effort in 1950. The X-10 experienced a successful first flight in October 1953 and later achieved speeds of over Mach 1.8. Three X-10s and seven XSM-64 weapon systems were manufactured prior to the program's cancellation in 1957. The Navaho effort is clearly recognized as contributing significantly to North American's success at winning the XB-70 competition for a Mach 3 strategic bomber in 1957. Jones (1980), p. 214; Miller (1983b), p. 84.

[18]Knaack (1978), p. 113.

[19]The Air Force had required that Douglas provide the plans and data for the X-3 to Lockheed. See Knaack (1978), p. 175, fn. 1.

Lockheed eventually succeeded in early 1953 by joining with the proponents of a lightweight fighter (LWF) and offering the Air Force a relatively small, high-speed interceptor design. Impressed by the maneuverability and speed of the simple, lightweight Russian MiG-15 during combat in Korea, some pilots and other elements within the Air Force had become increasingly critical of the trend toward costlier, heavier, more complex fighters, such as the F-86F, F-100, and F-102. Originally, Lockheed strongly opposed the LWF element within the Air Force and fought hard for acceptance of one of its more traditional fighter designs.[20] After the Air Force's continued rejections of its heavier design proposals, Lockheed finally joined forces with the LWF advocates and won an R&D contract for the 15,000-lb. XF-104 in early 1953.[21] The Lockheed design—particularly the adoption of a short, stubby wing planform instead of the delta that was widely favored at the time for high-Mach aircraft—drew heavily on NACA wind-tunnel tests and test data from the Douglas X-3, which had featured a similar wing planform.

The Korean War buildup also provided conditions favorable for the success of Republic's bid to develop a new supersonic fighter. The company's F-84F, an attempt to quickly modify and upgrade the existing straight-wing F-84 with swept wings, experienced considerable developmental delays during the early phases of the Korean War. Instead of further upgrading the F-84F, Republic proposed an all-new supersonic fighter design to the Air Force that would far exceed the F-84F in performance as a nuclear-capable fighter-bomber. In mid-1952, the Air Force approved development of Republic's design, designated the F-105.

Thus, during a period of less than two years between mid-1951 and early 1953, at the height of the Korean War, the Air Force authorized development of a total of six new supersonic fighters, which together later became known as the famous "Century Series" fighters. Analysts at the time pointed out that the most successful of these R&D programs, using the narrow measures of schedule and cost, were the North American F-100 and Lockheed F-104.[22]

North American benefited greatly from its earlier experience with the extremely successful F-86, on which the F-100 design was based (as well as the XF-93), and the supersonic aerodynamic studies it was conducting for the X-10 Navaho program. As shown in Figure 3.1, the Air Force procured more F-100s than any

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[20]Johnson (1960), pp. 51–53.

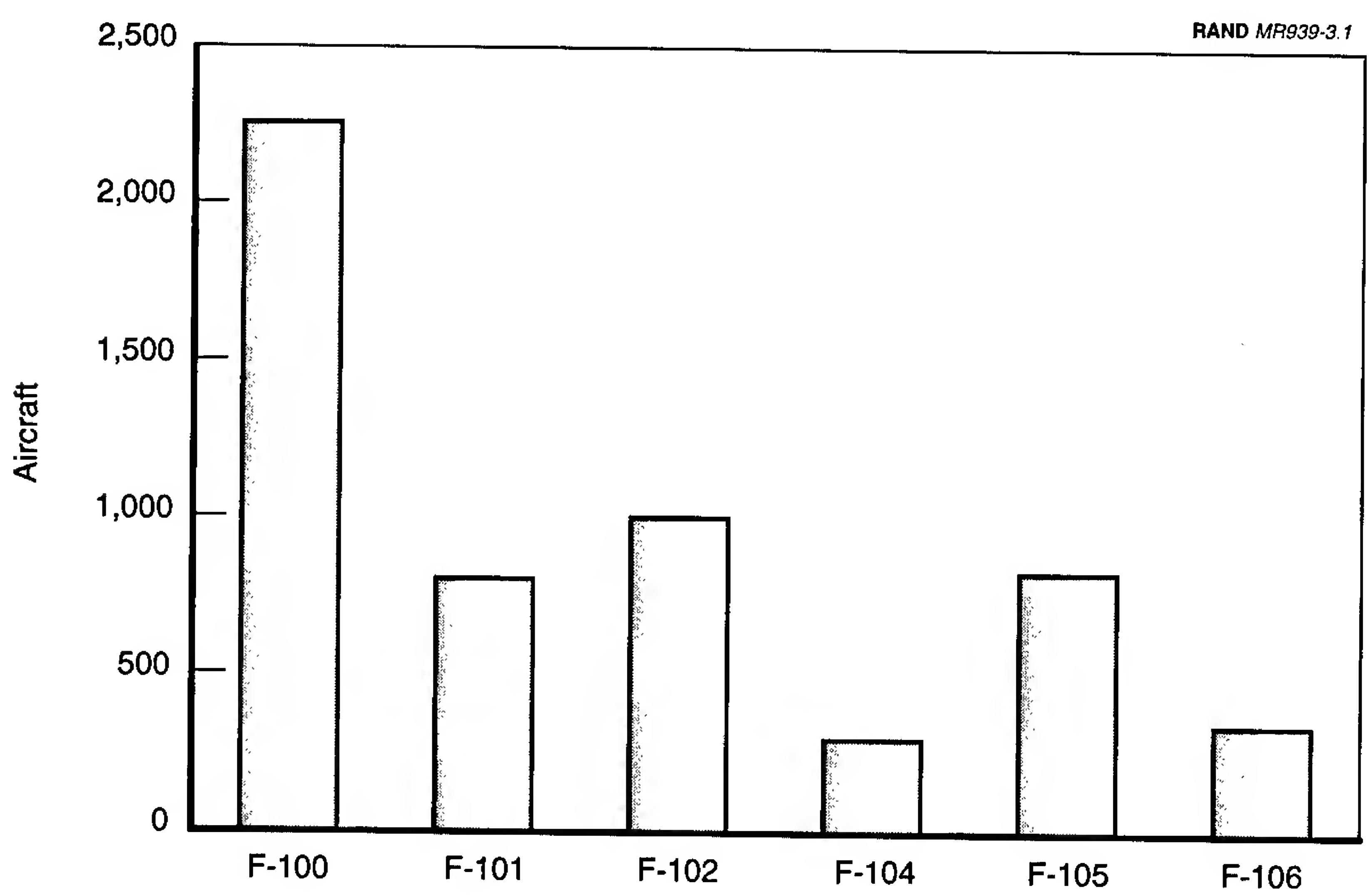
[21]Interestingly, the Air Force chose the Lockheed design over submissions from North American and Republic in part because of a desire to maintain a larger number of contractors with experience in fighter R&D. See Knaack (1978), pp. 175–76.

[22]Some observers have also pointed out that the F-100 experienced many "teething" difficulties as the design matured and that the Air Force purchased the F-104 only in very limited numbers.

other Century Series fighter. Indeed, the F-100 stands out as the first operational supersonic fighter in the world.

Lockheed also drew on its long experience with jet fighters, as well as on the data from the Douglas X-3 Stiletto program,[23] and benefited greatly from the unfettered R&D approach of its famous "Skunk Works" in Burbank. The dominant view in the Air Force, however, opposed the LWF concept because of its limited range and payload, and the F-104 was procured only in relatively small numbers.

The Convair F-102 program experienced significant R&D delays, many of which stemmed from engine problems and the overambitiousness of its planned automated avionics subsystems. Convair also encountered serious aerodynamic design difficulties with the fuselage shape, which had to be redesigned in



SOURCE: Knaack (1978).

Figure 3.1—Air Force Procurement of Century Series Supersonic Jet Fighters, 1950s–1960s

[23]Although the X-3 program failed to achieve its objectives because of problems with engine performance, the test aircraft made major contributions to the understanding of high-speed fighter aerodynamics, and the resulting data were distributed throughout the U.S. industry. Francillon, (1990a), p. 454.

accordance with the "area rule" concept.[24] By the end of 1954, however, the aerodynamic problems had been solved, and the F-102 went on to become a successful interceptor, as did the higher-performance F-106. As shown in Figure 3.1, the F-102 was procured in the second largest numbers of any Century Series fighters. There is no question that Convair's experience developing the delta-wing XF-92 contributed directly to that success.

Republic's F-105 eventually became the USAF workhorse in Vietnam for fighter ground attack and was procured in the third largest numbers of the Century Series fighters. The F-105 design clearly drew on the long Republic tradition, dating back to the P-35 and P-47, of developing large, heavy, ground-attack fighters.

McDonnell's F-101 evolved into a successful all-weather interceptor and reconnaissance fighter and was procured in numbers about equal to the F-105. McDonnell drew not only on its experience with the XF-88 to develop the F-101 but also on that gained from its successful Navy fighter R&D programs.

By the late 1950s, following the selection of the contractors to develop the Century Series fighters, it seemed that North American and Convair were pulling ahead of the other contractors as the leading overall developers of combat aircraft for the Air Force, as they continued to build on their now extensive experience in jet-fighter R&D.

In 1953, North American had chosen an incremental design approach by developing a new supersonic fighter-bomber, the YF-107, which was inspired by its earlier F-100 and F-86 designs. Although the YF-107 performed well, it offered no significant performance improvement over the F-105 in those areas the Air Force specifically sought and thus was not procured.[25]

Much more important—it seemed at the time—were North American's big contract victories in 1957. In June of that year, the Air Force awarded North American a development contract for the most fantastic fighter yet conceived. This fighter, the XF-108 Rapier, was planned to be a long-range all-weather interceptor with a combat speed in excess of Mach 3 and a combat ceiling of

[24]The area-rule concept predicts drag at transonic and supersonic speeds based on the relationship of fuselage cross section and surface area. NACA engineers did not verify this concept until December 1952, well after the original F-102 design had been formulated. Knaack (1978), p. 163, fn. 5.

[25]The YF-107 design was originally based on the F-100 (and originally given the F-100B designation) but evolved into virtually a new design incorporating several new technological features including a variable-geometry inlet system, an all-moving vertical tail, and a fully integrated semisubmerged payload. In a fly-off, it performed better in terms of speed (with afterburners) and maneuverability than the F-105. However, the F-105 was a better air-to-ground configuration and was so used in Vietnam.

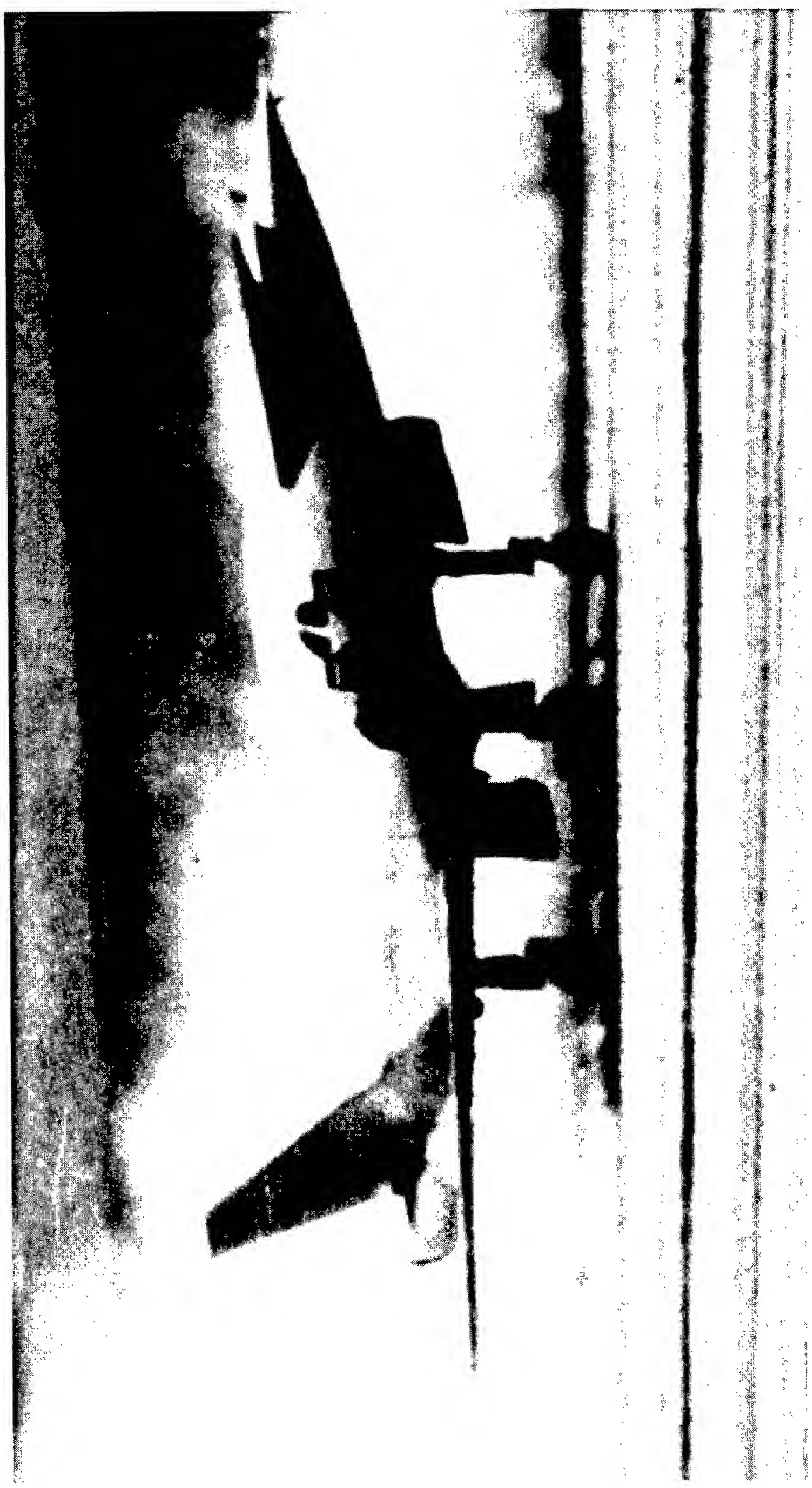


Photo 3.6—The X-10, built under the auspices of the SM-64 Navaho project, helped provide North American with extensive experience in high-speed supersonic flight in the mid-1950s.

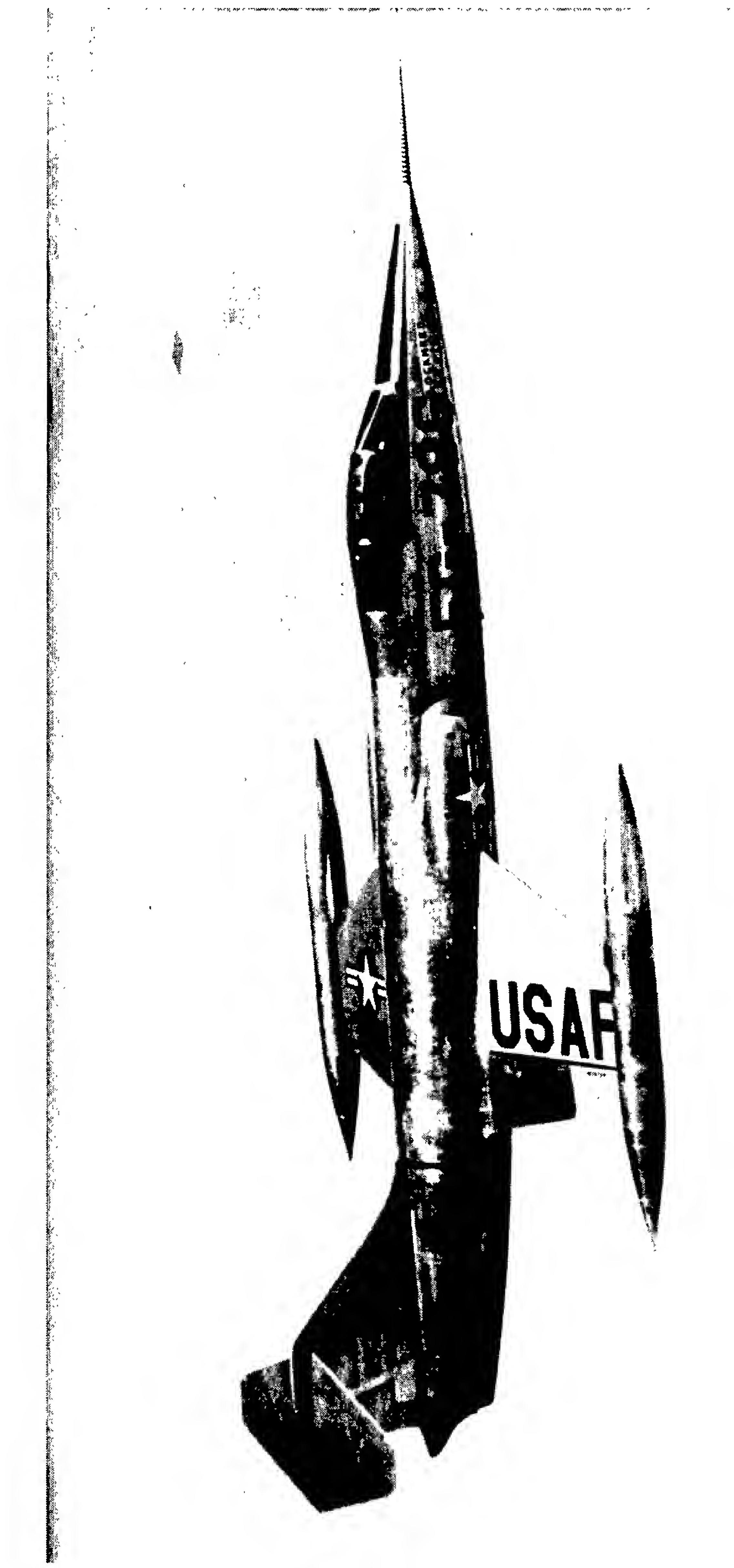


Photo 3.7—The Mach 2+ prototype Lockheed XF-104 first flew in February 1954. The F-104 Starfighter was procured in relatively small numbers by the U.S. Air Force and became the last Lockheed-designed fighter to see operational service before the stealth era.

70,000 feet. Six months later, North American also won the hotly contested competition to develop the Air Force's next strategic bomber and partner of the XF-108, the Mach-3 XB-70. In September 1955, the El Segundo company had already won the developmental contract for the X-15 test aircraft, which NACA intended to use to explore very high-speed, high-altitude flight at speeds of Mach 4 to 10. Thus, by the end of 1957, the developer of the famed P-51 Mustang and F-86 Sabre had also won the two most important Air Force competitions of the late 1950s—or so it seemed at the time—for both the next-generation fighter and bomber. With its X-10 Navaho, F-100, X-15, YF-107, XF-108, and XB-70 programs, North American could justifiably be viewed at the time as the world's leading developer of very-high-speed military aircraft.

Despite their developmental problems, Convair's F-102 and F-106 were procured in large numbers and served as the backbone of the USAF interceptor force. They represented the first attempt to develop a fully integrated and automated fighter-interceptor weapon system. Convair's Mach-2 B-58 Hustler became the world's first supersonic bomber and represented an enormous leap in aerospace technology. The Texas firm, building on its tradition as the developer of one of the most famous combat aircraft of World War II, had clearly parlayed the original Lippisch delta-wing data into innovative designs that had won it a leading position in both fighters and bombers.

Convair's rise as a technologically innovative fighter and bomber developer contrasted with the beginning of the decline of one of the great historic leaders in fighter R&D. When the Air Force canceled Republic's overly ambitious XF-103 program in September 1957, this famed developer of fighters began a long decline from which it never fully recovered. Republic, which had specialized almost entirely in developing fast, heavy, fighter-attack aircraft, would find it increasingly difficult to diversify to other types of aircraft or to adjust to the radically changed procurement environment for fighters that emerged later in the 1960s.

With the failure to garner widespread Air Force support for the LWF concept as represented by its F-104, Lockheed began to fade as a leading mainstream fighter contractor. Lockheed's Skunk Works, however, established itself in the highly specialized niche area of developing unique, high-performance reconnaissance aircraft. As a far more diversified aircraft company than Republic, Lockheed was thus able to draw on its extensive fighter experience to move into a related area of high-altitude, high-speed reconnaissance aircraft. This area would provide it with unique firm-specific capabilities that years later would catapult Lockheed into a leadership position again in fighter R&D.

Northrop, like Lockheed, staked its future in the early 1950s on the LWF concept. As a result, this Los Angeles–based company, which had always been con-

sidered to be rather eccentric technologically, never won a mainstream development contract for a second-generation supersonic fighter. Northrop achieved considerable success in directly related areas, however, by developing its N-156 LWF concept into the T-38 Talon. The T-38 quickly became the standard U.S. Air Force supersonic trainer and later evolved into the very successful and widely exported F-5 Freedom fighter series.

DEVELOPMENT OF NAVY SUPERSONIC FIGHTERS

The Navy continued to trail behind the Air Force in fighter R&D during the supersonic era of the 1950s, as it had during the initial period of jet-fighter development. The Navy supported a far smaller overall number of supersonic fighter R&D efforts and such related technology development and demonstration programs as cruise missiles and X-planes, which were so important for building the experience and capability base for the success of Air Force programs. Furthermore, the Navy faced particularly difficult technical problems in trying to develop supersonic fighters that could be launched and recovered from the relatively small space available on aircraft carriers. In addition, the Navy unfortunately spent some of its scarce R&D funds with little tangible result on several unusual concepts, such as Convair's XF2Y seaplane jet fighter and large jet-powered transport seaplanes. Nonetheless, the Korean War had convinced the Navy that it must support the development of cutting-edge jet-fighter technology. The Navy was determined not to be caught again in a new conflict with lower-performance aircraft, as it had been at the beginning of the Korean conflict.

In the particularly challenging circumstances the Navy faced, however, Grumman—the Navy's premier fighter developer since the 1930s—stumbled and temporarily slipped from its leadership position during this period while experimenting with novel technologies. Douglas withdrew entirely from fighter development. Surprisingly, two secondary Navy-oriented contractors—McDonnell and Vought—ended up developing not only successful new Navy fighters but also two of the most important and famous supersonic fighters of the 1950s and 1960s, versions of which were eventually procured in large numbers by the Air Force.

Grumman's difficulties began when it attempted to develop the Navy's first carrier-based transonic fighter, the XF10F Jaguar. Like Convair with the XF-92, Grumman had originally chosen a delta-wing configuration—derived from its F9F design—as best for transonic flight. But the high Navy performance requirements and the limited space available on carriers forced Grumman to drop this configuration in 1950 in favor of variable-sweep or variable-geometry wings. In its straight-out position, such a wing would make short takeoffs and slow landing speeds possible for carrier use. In its swept-back position, it

would permit high-speed transonic performance comparable to land-based fighters.[26] In the late 1940s, Bell had experimented extensively with variable-geometry wings with its NACA X-5 technology demonstrator, based on the German Messerschmitt P-1101 captured at the end of the war. Unfortunately, variable-geometry wings posed many difficult technical problems. Neither Bell nor Grumman was able to resolve these problems satisfactorily in the early 1950s. The XF10F program continued with extensive flight testing from 1951 through 1953 but was finally canceled.[27]

During the Korean War, the Navy issued operational requirements for both a supersonic long-range all-weather fighter interceptor and a simpler supersonic day fighter for use on carriers. With problems continuing to arise on the XF10F flight-test program, Grumman moved ahead with another more traditional swept-wing design, also derived from the F9F, in the hopes that it could be developed into the first shipborne supersonic fighter. The Navy approved full-scale development of this new design, labeled the F11F Tiger, in early 1953. Because of engine development and design problems, however, the F11F failed to meet contractual performance requirements. The fighter was later procured in limited production quantities and became the Navy's first transonic carrier-based fighter. However, it never attained the operational capability of sustained supersonic flight.[28]

As a backup to the Grumman programs, the Navy also authorized Douglas in March 1953 to develop a variant of its successful F4D Skyray into an all-weather supersonic fighter for carrier operations. As the program progressed, the aerodynamic requirements of supersonic flight necessitated so many design changes that the design evolved into an entirely new fighter, designated the F5D Skylancer. Progress was slow, and although the flight-test prototype—first flown in April 1956—performed reasonably well, the Navy canceled the program shortly thereafter because of the emergence of better options.[29]

Thus, the two historic leaders in naval military shipborne aviation had faltered in their initial attempts to develop supersonic fighters for carrier use. One of the reasons the F5D was canceled was because a secondary Navy contractor—and developer of the famed F4U Corsair—had already succeeded in producing a potentially first-rate supersonic day fighter that performed as well as the Skylancer could be expected to if it was fully developed. Although its early subsonic jet fighters met with mixed success at best, Vought's XF8U design won the

[26]Another motivation for the variable-geometry wing design was to improve visibility during takeoff and landing by allowing the fuselage to stay more level.

[27]A full description of these and other early variable-geometry programs is found in Perry (1966).

[28]Green and Swanborough (1994), pp. 268–269.

[29]Francillon (1990a), pp. 506–508.

Navy competition for a supersonic shipboard day fighter in 1953 in competition against seven other design proposals. Vought's design made use of an ingenious variable-incidence swept wing to help keep the fuselage more level during takeoff and landing, thus improving the visibility during these critical flight phases. With a first flight in March 1955, this relatively light and simple day fighter eventually proved highly successful. The Navy ultimately procured over 1,200 production versions of the F8U Crusader, keeping production lines open well into the 1960s.[30] A radically modified version—called the A-7 Corsair II—became the standard Air Force attack aircraft in the late 1960s.[31]

Despite the success of the F8U, the Navy still needed its long-range all-weather supersonic fighter-interceptor for use aboard carriers. By 1955, it was becoming increasingly apparent that Grumman's F11F (first flown in July 1954) and Douglas's F5D might not be able to fill that role adequately. The Navy then turned to the still-young McDonnell corporation, which was busy designing a new naval fighter-attack aircraft.

As noted above, in 1953 the Navy awarded its most important fighter R&D contracts to Grumman for development of its first all-weather supersonic fighter (with a backup contract to Douglas) and to Vought for its supersonic day fighter. McDonnell had competed in these competitions but lost. The only remaining Navy project for the company was development of a jet attack fighter to replace the prop-driven Douglas AD-1 Skyraider. This seemed reasonable at the time because the company's great success, the F2H Banshee, had been primarily a ground-attack fighter-bomber. Furthermore, its F3H Demon air-superiority fighter was having serious developmental problems. Indeed, McDonnell's design submission that lost to the Vought F8U had been derived from its troubled F3H Demon design. Thus, it was not surprising that McDonnell turned its efforts toward designing an attack fighter. In September 1954, a McDonnell design for a new jet attack fighter, designated the AH-1, won a developmental contract over design proposals from Grumman and North American. The same month, McDonnell celebrated the first flight of its F-101 Voodoo for the Air Force, an aircraft that eventually would greatly influence its new Navy contract.[32]

Fearing the possible failure of the ongoing Grumman and Douglas fighter development efforts, the Navy asked McDonnell in 1955 to change its AH-1

[30]A Crusader variant, the F-8E(FN), was also purchased by the French Navy to serve as its standard carrier-based air-superiority fighter. These fighters are expected to remain in service on French Navy carriers until around the year 2000.

[31]See Jones (1977), pp. 312–319.

[32]Francillon (1990b), pp. 175–176.

Photo 3.8—Featuring an innovative air intake position above and behind the cockpit, the North American YF-107A flew in competition with the Republic F-105 Thunderchief for selection as a supersonic deep-penetration nuclear strike fighter. The YF-107A was canceled in 1956 after selection of the Thunderchief. The YF-107A was North American's last flying fighter design.

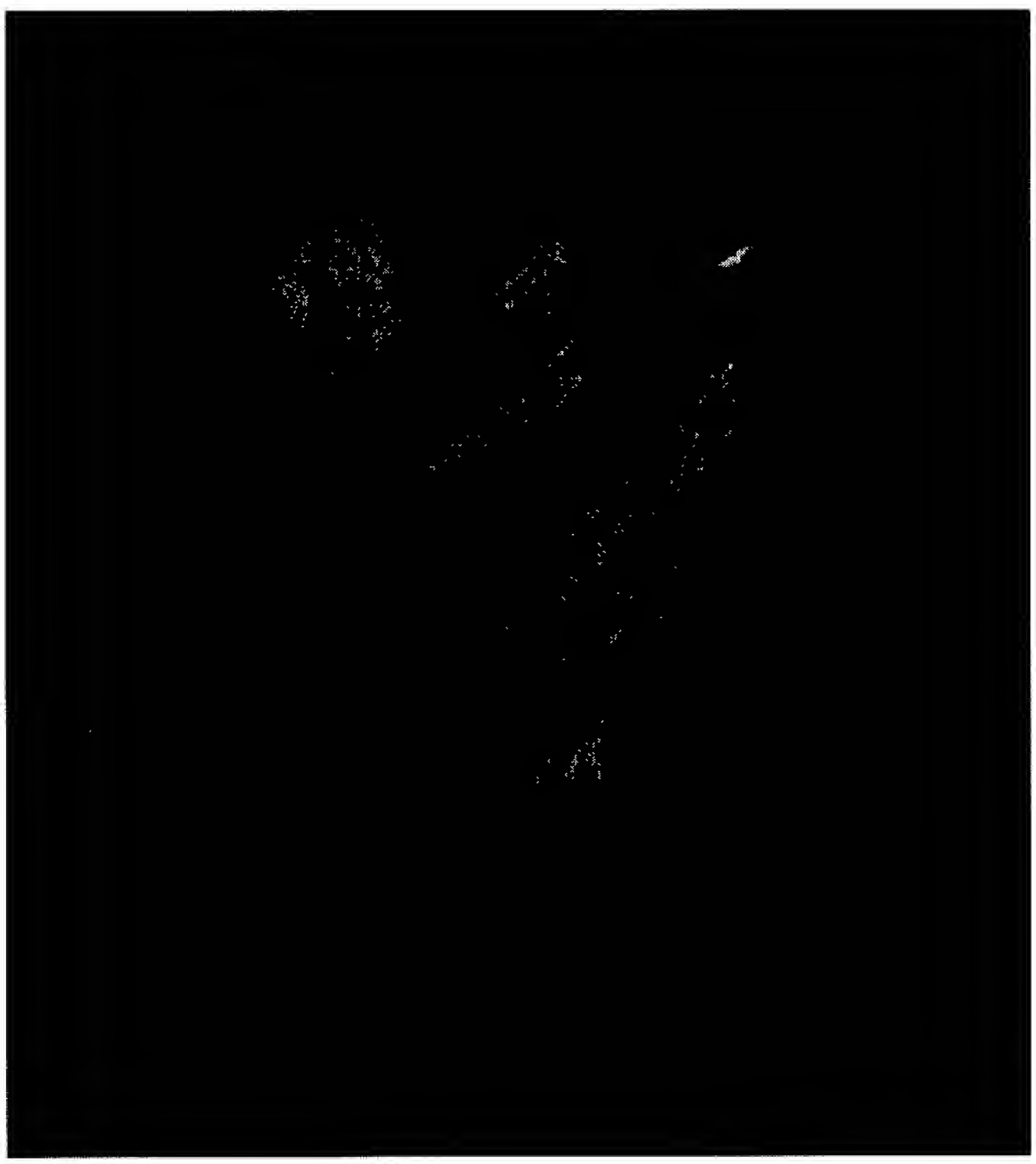


Photo 3.9—The Douglas F5D Skylancer, a development of the F4D Skyray. The Navy canceled the Skylancer program in 1956 after flight testing four prototypes.

design from a single-seat, cannon-armed attack aircraft, to a two-seat, missile-armed, long-range supersonic interceptor, as a fallback for the other programs. The new design, later designated the F4H Phantom II, evolved into one of the most successful and well-known jet fighters of the postwar era. Later versions became the backbone of the U.S. Air Force tactical fighter force, as well as many foreign air forces, in the 1960s and early 1970s. The Phantom has been described as "unquestionably the most significant and successful Western fighter of the sixties."[33]

Ironically, the great success of McDonnell's F4H Phantom II is attributable in large part to the company's earlier experience with the ill-fated Demon and other Navy programs, as well as to the extensive experience acquired on earlier Air Force supersonic fighter R&D programs. As mentioned earlier, McDonnell's F3H Demon, approved for development in 1949, had been slated to serve as the Navy's first swept-wing carrier-based fighter that was fully competitive with land-based fighters. Plagued by engine development problems, the Demon never proved fully satisfactory. McDonnell, however, gained critical experience working out the problems on the Demon program. But much more important was the experience built up beginning in early 1952 when the Air Force asked McDonnell to transform the XF-88 into the long-range supersonic F-101 escort fighter.

The Voodoo, which first flew in September 1954, was the first operational fighter with variable inlets and represented the largest, most powerful, and fastest supersonic fighter to date. By mid-1955, when the Navy changed its AH-1 requirement and asked for a long-range supersonic fighter-interceptor instead of an attack aircraft, McDonnell had already had nearly a year of experience flight testing the F-101.[34] Drawing heavily on the basic Voodoo configuration, design, and flight-test data, McDonnell went on to design the F4H Phantom II, which first flew in May 1958.[35]

At this point the F4H had to fend off a worthy competitor. Given its experience, the Navy in 1957 wisely authorized a backup R&D program for a competitive Mach-2 interceptor derived from the successful Vought F8U. The F8U-3 Crusader III, which first flew a month after the Phantom, was in reality a virtually all-new high-performance Mach 2+ fighter-interceptor. Although the prototype F8U-3 performed well and experienced only one serious problem,

[33]Green and Swanborough (1994), p. 367.

[34]These flight tests had by this time revealed several aerodynamic, structural, armament, and propulsion problems with the F-101A. McDonnell engineers were already working hard to correct these problems when serious development started on the Phantom II. See Knaack (1978), pp. 138–139.

[35]See Sweetman (1984), pp. 5–6; Francillon (1990b), pp. 175–178; and Mason (1984), pp. 12–22.

caused by its powerplant, during flight testing, the aircraft was rejected in favor of the Phantom.[36]

Thus, at a time when the Air Force was pushing many of its contractors to the edge of the technological envelope by asking them to develop Mach 3+ superinterceptors and bombers, the Navy gave McDonnell the opportunity to develop its second supersonic fighter in the same general performance and technology class as its first. This opportunity permitted McDonnell to build and improve more directly on its experience with the F-101, as well as with the F3H Demon. The only other developer of a Century Series fighter given a comparable opportunity was Convair when it developed the F-106 based on the F-102, but only because the F-102 had fallen so far short of original expectations. Not surprisingly, the F-106 far outperformed its predecessor.

OVERALL TRENDS FOR PERIOD 1, 1945–1961

Based on this broad historical survey of the period when American companies developed the first and second generations of jet fighters, several major themes emerge: *continuity, specialization, and incrementalism*; *competition with multiple players and prototyping*; and *Air Force and NACA technology leadership.* All these trends combined to produce an almost uninterrupted continuum of fighter R&D experience throughout the period for the leading fighter contractors, as shown in Figures 3.2 and 3.3. The figures also provide insights into the importance of system and firm-specific experience during this period.

Continuity, Specialization, and Incrementalism

With the two notable exceptions of Convair and McDonnell, the leading fighter developers at the end of the 1950s were the same as those that emerged during World War II, as shown in Figures 3.2 and 3.3. North American, Republic, and Lockheed held leadership positions in Air Force fighter development at both ends of Period 1. Convair was a new leader, but its predecessors—Consolidated and Vultee—played important roles during World War II in bomber and fighter development. Grumman and Vought were also major Navy fighter developers at both the beginning and end of the earlier period. McDonnell, however, arose as a new pace setter by the end of Period 1. Yet McDonnell did not achieve its position suddenly; it had begun its tradition of excellence in jet-fighter R&D in the latter days of World War II, when it helped pioneer jet-fighter development for the Navy.

[36]Jones (1980), pp. 314–317.

Photo 3.10—In May 1953, the Navy selected the Vought F8U-1 Crusader for development as the first carrier-based supersonic fighter. First flown in March 1955, the Crusader proved to be a highly successful fighter and was procured in large numbers. Versions of the Crusader were operated by the French navy into the 1990s.

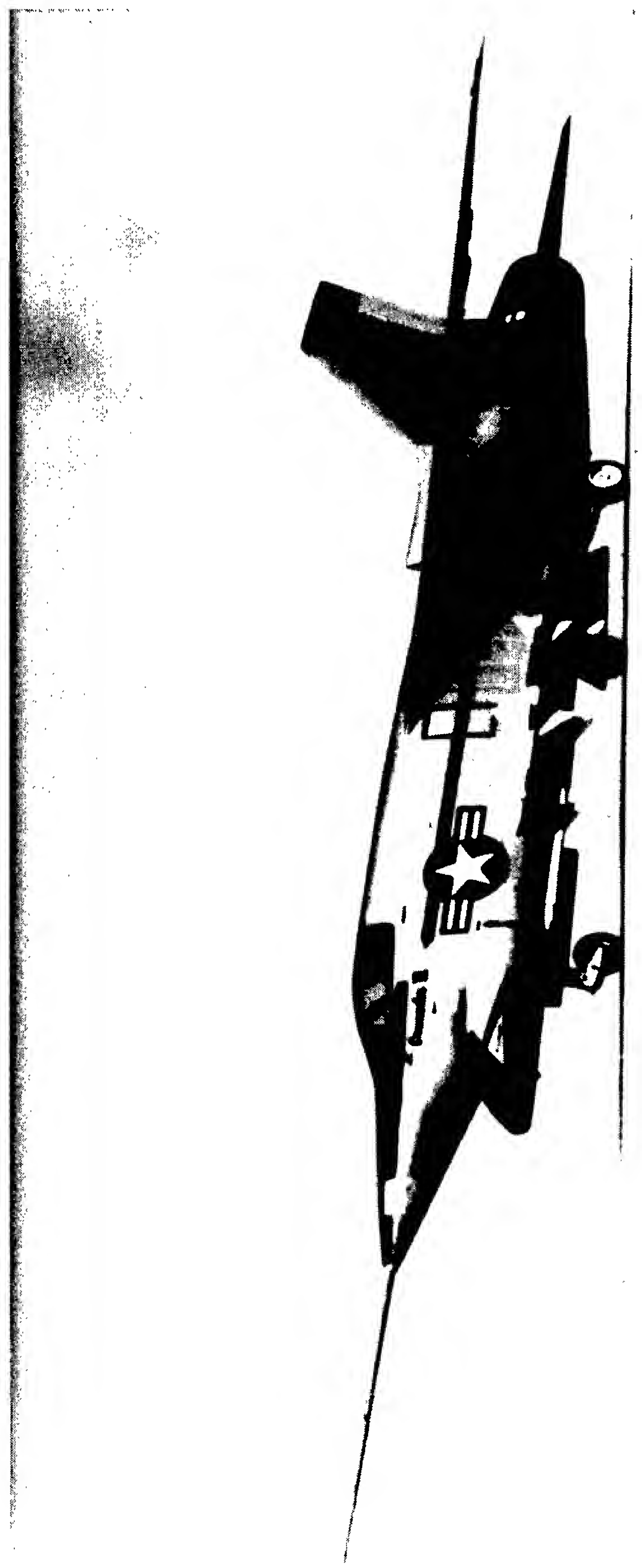
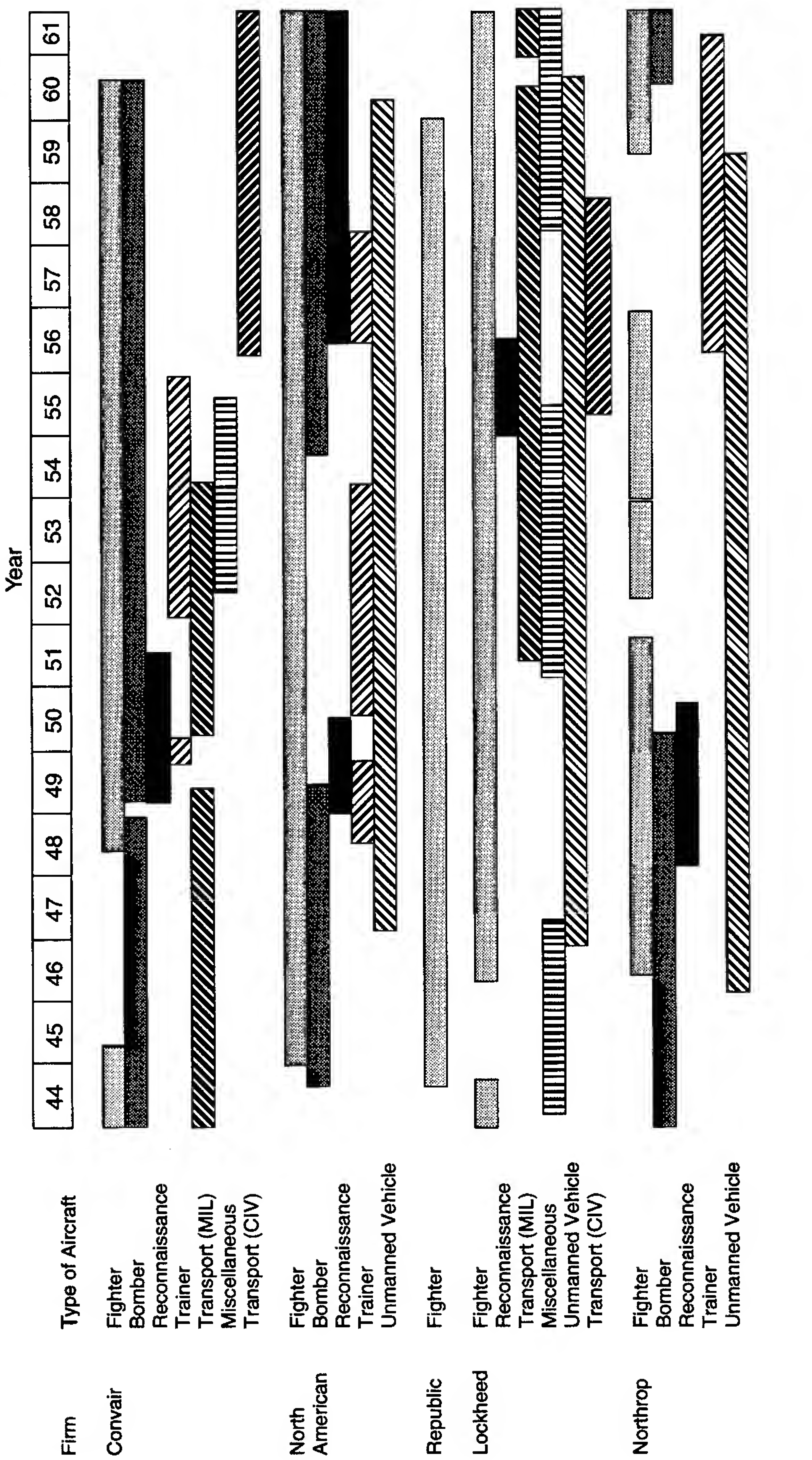


Photo 3.11—Vought developed the all-new F8U-3 Crusader III in the late 1950s to compete with the McDonnell F4H-1 Phantom II for selection as the Navy's next carrier-based fleet air-defense fighter. Only three examples of the Mach 2.5 fighter flew, since the Navy canceled the program after selection of the Phantom in late 1958.

ADDENDUM

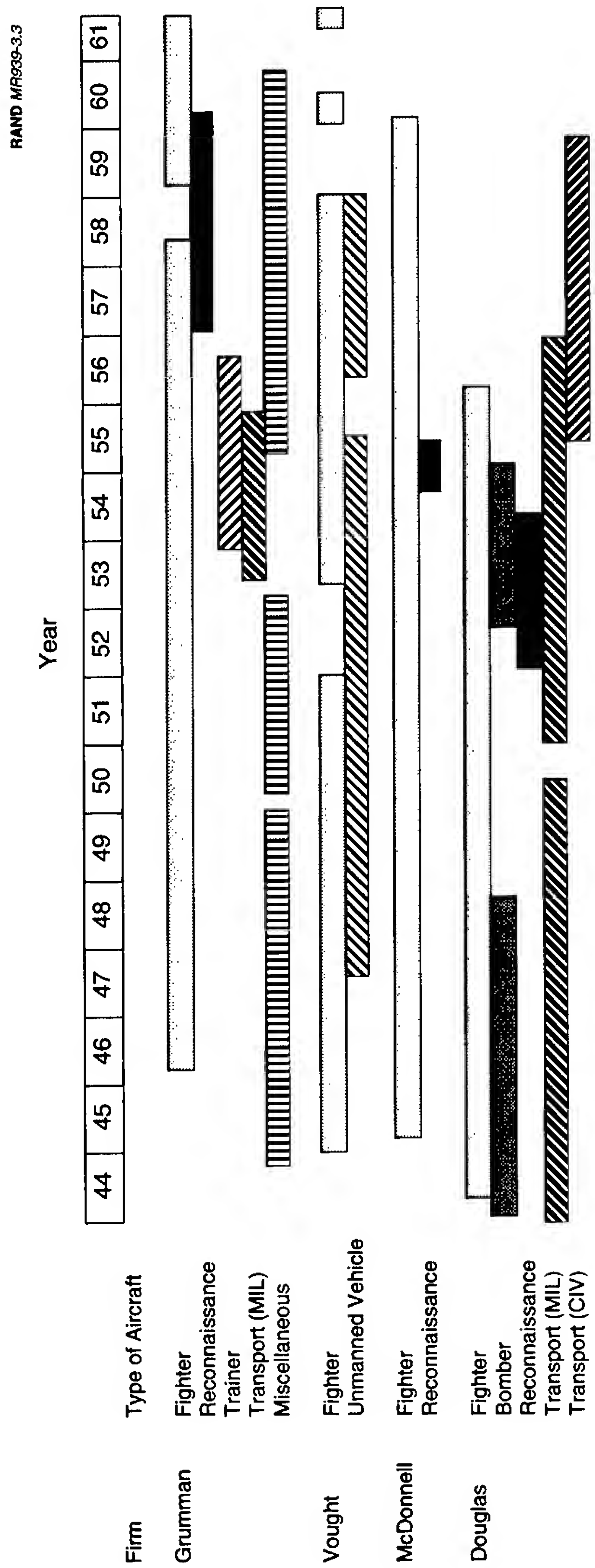
The Cutting Edge: A Half Century of U.S. Fighter Aircraft R&D
Mark A. Lorell and Hugh P. Levaux

For the sake of completeness, all the timeline figures showing the experience of firms in each of the three historical periods (Figures 3.2, 3.3, 5.1, 5.2, 6.2, and 6.3) contain all program categories, as delineated in the database listings in Appendix B. However, the figures showing the breakdown of program types as a percentage of each firm's total experience for each historical period (Figures 3.4, 5.3, and 6.4) focus only on new program starts that resulted in series production. Therefore, the latter three figures exclude the program categories labeled in Appendix B as "upgrades" and "X-planes."



SOURCE: RAND database.

Figure 3.2—R&D Experience of Leaders in Air Force Fighter R&D in Period 1



SOURCE: RAND database.

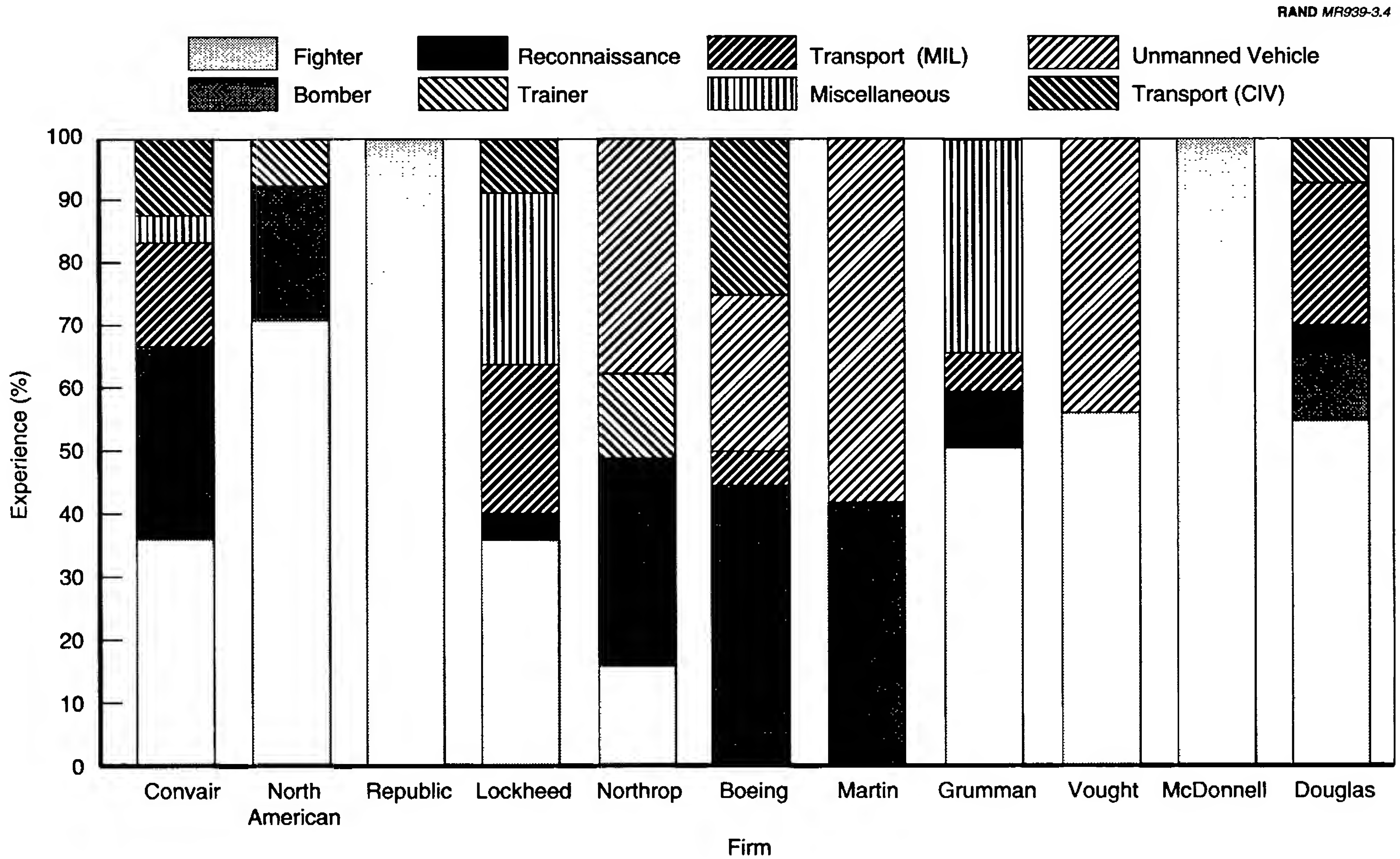
Figure 3.3—R&D Experience of Leaders in Navy Fighter R&D in Period 1

The centrality of continuity indicates that system-specific experience remained critical during this period. The emergence of two relatively new leaders—Convair and McDonnell—at the beginning of this period suggests that periods of radical technological change lower entry barriers and provide openings for new, innovative entrants with specialized firm-specific capabilities. Such periods of radical technological change include the transition from piston to jet propulsion and the development of supersonic flight.

The leading fighter developers during this period devoted significant percentages of their overall corporate efforts to fighter R&D. When measured in terms of the total work days between an initial hardware development start and a production start for any given project, 40 percent or more of the days most of the leading fighter developers spent on hardware R&D were spent on fighter development, as shown in Figure 3.4. Two leaders—McDonnell and Republic—worked almost exclusively on fighter R&D, while North American's and Vought's numbers exceed 50 percent. Convair and Douglas stand at about 50 percent, and Grumman goes above 50 percent. If bomber R&D is added, North American rises above 90 percent, and Convair and Douglas rise to about 65 percent.

Interestingly, little correlation exists during this period between success in large commercial transport aircraft and fighters or supersonic bombers. Among the major prime contractors, only Convair, Lockheed, and Douglas show any significant large commercial-aircraft development work. Of these, only Convair could be considered a first-rank fighter supplier by the late 1950s. Yet Convair's major airliner programs—the 880 and 990 transports—proved to be commercial failures. Douglas had essentially withdrawn from fighter R&D at the time the DC-8 was proving to be a successful commercial jet airliner program. Boeing, building on its experience with subsonic jet bomber and military transport development (B-47, B-52, C-135), began emerging as the leading developer of the new generation of commercial jet transports. Yet, at the same time, Boeing moved further and further away—although not by choice—from its former tradition in the 1930s of developing fighters.

Fighter contractors also specialized in other ways. Many leaders in fighter R&D focused even more narrowly on a specific type of fighter or on a specific design approach to fighters. When companies tried to diversify into different areas, they risked failure. For example, Republic exclusively developed large, heavy, ground-attack fighters (P-35, P-47, F-84, F-105). When it tried to develop the XF-103—a Mach-3 high-altitude interceptor—it failed. From the late 1940s through the late 1950s, Convair designers never strayed from their favored delta-wing design configuration in any of their major fighter and bomber programs.



SOURCE: RAND database.
NOTE: Bell, Curtis, and Ryan not shown.

Figure 3.4—Breakdown by Firm of Share of Experience by Types of Aircraft Relative to Firm's Total Experience in Period 1

In addition, most leading fighter companies primarily developed either Air Force or Navy fighters, but not both types. The five leading Air Force fighter contractors—Convair, North American, Republic, Lockheed, and Northrop—developed and flew a total of 29 distinct fighter and bomber designs. Yet only one production fighter—the FJ-1 Fury—was developed for the Navy. These companies flight-tested three other prototype fighter designs for the Navy, but none of them won production contracts. In addition, these were high-risk long-shot programs. Only one bomber—the North American A-5—out of seven production or prototype bombers went to the Navy.

Grumman, Vought, and Douglas developed fighters exclusively for the Navy. Douglas flew two bomber designs developed for the Air Force, one of which—the RB-66—was procured. This bomber, however, was a modification of the A-3D developed originally for the Navy. McDonnell remained the sole developer of Navy fighters during this period that also won a significant Air Force fighter R&D project.

Finally, almost every leading company developed fighter designs in an evolutionary fashion that built on previous successful fighter or technology demonstrator designs. This is particularly evident with such highly successful companies as North American, Convair, McDonnell, and Grumman. Clearly, contractors learned from experimenting through flight testing and developing specific designs, then sought to refine or expand on the design concepts with which they had built up experience.

The continuity of R&D leadership, the various forms of specialization among contractors, and the clear preference for incrementalism all seem to confirm the central importance of both system- and firm-specific experience during this period.

Competition and Prototyping

The 1940s and 1950s were characterized by intense competition at the design stage among large numbers of credible contractors for nearly every major fighter and bomber contract. This competition often continued well into the hardware development stage. Such competition may have contributed materially to the high degree of innovation in design and technology during this period and to the overall success of most fighter R&D efforts.

The five main Air Force and four main Navy fighter contractors often crossed over and competed in design competitions sponsored by the other service, and sometimes won these competitions, as in the case of McDonnell and the F-101. Leading contractors were always in danger of losing their position if they did not perform well, and second-tier contractors had a good chance to move to the

forefront if they offered novel technology or designs. The services appear to have carefully nurtured this competition. For example, Grumman was generally viewed as the favored Navy fighter contractor. But when it failed to meet performance requirements with its XF10F and XF11F programs, the Navy awarded its plum contract for a supersonic fighter to McDonnell, perhaps in part because of the St. Louis firm's success in developing the supersonic Air Force F-101.

Perhaps even more importantly, the services sometimes kept full competitions going well into the hardware-development stage. Good examples of this are the fly-off between the McDonnell XF-88, Lockheed XP-90, and North American XF-93, or the competition between the McDonnell F4H and Vought F8U-3. Alternatively, the services sometimes supported the development of special proof-test flying prototypes before entering into full-scale production, as in the case of the Convair XF-92. Over the years, RAND research has indicated that this type of prototype competition improves program outcomes in terms of performance, cost, and schedule.[37]

Air Force and NACA Technology Leadership

Finally, the history of fighter R&D from 1945 to 1961 indicates that the U.S. Air Force and NACA provided critical technology leadership. The Air Force pushed much stronger than the Navy for the development of both effective operational jet fighters and combat aircraft capable of sustained supersonic flight. The Air Force and NACA devoted considerable funding and other resources to support the X-plane program, a long series of extraordinary developmental efforts using experimental flight-test aircraft, which was without precedent in the history of aviation. In addition, both the Air Force and the Navy supported many of their own technology-demonstration flight-test programs for proof testing new technologies or design concepts.

The primary technology drivers during this period were revolutionary advances in propulsion systems and the development of very-high-speed aerodynamics and the associated airframe materials and structures. Extensive wind-tunnel testing, theoretical research, and a variety of other critical tasks were undertaken by engineers and scientists at NACA facilities, at the service research laboratories, and in industry. Government scientists helped develop and refine such key aerodynamic concepts as both the swept- and delta-wing planforms, variable-geometry wings, and variable air inlets. NACA scientists discovered

[37]For example, see Klein et al. (1958); Perry (1972); Smith et al. (1981), and Lorell (1989).

the "compression lift" concept[38] in 1956 and helped refine the "area rule" concept that made very-high-speed fighters possible.

It is not likely that the great advances in fighter performance that took place between 1945 and 1961 would have been possible without the consistent support of the services and NACA for a research program of unprecedented magnitude.

The overall situation in the late 1950s, however, would soon be significantly altered by a variety of forces. First, the declining marginal returns and exploding costs of developing ever-faster and higher-flying fighters and bombers led government leaders and the services to rethink roles and missions for fighters. This ultimately led to a series of acquisition reforms that had a profound effect on the fighter industrial base. Second, the Kennedy administration instituted a major shift in national doctrine away from massive retaliation toward flexible response, which led to significant changes in the operational environment and the performance requirements for fighters and bombers. Finally, combat experience in Vietnam and elsewhere caused a painful reevaluation of fighter requirements and performance goals. These changes and their implications are discussed in more detail in the next chapter.

[38]An aerodynamic phenomenon discovered in 1956 that postulated dramatically increased lift-to-drag ratios at high supersonic speeds. Knowledge of this concept was critical for the design of very-high-speed military aircraft, such as the XB-70 bomber.

Chapter Four

THE 1960s AND 1970s: ACQUISITION REFORM, DOCTRINAL FERMENT

INTRODUCTION

The first period of jet-fighter R&D, as discussed in the previous two chapters, can be characterized as a time of revolutionary technological change. The second period—which stretches from the early 1960s through the mid-1970s—also witnessed new technology developments and capability improvements, including fly-by-wire (FBW) flight-control systems, negative static stability, operational variable-geometry fighters, the beginnings of stealth, and sustained Mach 3+ flight. Nonetheless, none of these technological advances transformed the basic fighter platform to an extent comparable to that caused by the introduction of the jet engine and supersonic flight in the 1940s and 1950s. Despite great technological advances, the second period might best be broadly characterized as a time of unprecedented intellectual ferment, debate, and disagreement over basic fighter performance and design goals, mission roles, doctrine, and operational concepts. This debate led to a shift in emphasis from heavy, fast, multirole fighter-attack aircraft, to lighter, more agile, specialized air combat fighters. At the same time, escalating costs led to increasing attempts to reform the weapon-system acquisition process.

This intellectual ferment and debate were in part caused by dramatic changes in national security doctrine and weapon system procurement policies implemented by the Kennedy administration. Upon entering office, Kennedy's Secretary of Defense, Robert McNamara, almost immediately began implementing fundamental changes in doctrinal emphasis and procurement style from those of the 1950s. In the area of strategy and doctrine, the Kennedy administration placed increased emphasis on the importance of the "conventional option," stressing the ability of the armed forces to fight conventional and limited wars in a nonnuclear environment. McNamara and his "Whiz Kids" at the Pentagon were also determined to impose much greater discipline and rationality on the overall defense planning and budgeting process. The new Pentagon managers were particularly interested in reforming the pro-

cess by which the services generated new weapon-system performance requirements and developed and procured new hardware.[1]

McNamara's push to rationalize the procurement process was in part a response to technology and cost trends in the 1950s. The rapidly increasing speed, weight, and technical complexity of first- and second-generation fighters and bombers resulted in a dramatic escalation in R&D and procurement costs, (see Tables 3.1 and 3.2). As jet aircraft engine and airframe technology passed out of the early innovation stage and began to mature, each new increment of improvement in speed and altitude capabilities became increasingly challenging technologically and much more expensive. The growing R&D costs and increasing technological difficulties encountered on such fighter and bomber programs as the F-105, F-106, and B-58 led analysts to question whether even more technologically ambitious programs, such as the Republic F-103, North American F-108, and XB-70, were really feasible and cost-effective.[2]

With costs rapidly mounting, defense planners concluded that the large number of full-scale development and prototype technology demonstration programs characteristic of the 1950s could no longer be financially sustained. The Pentagon sought to reduce what it considered to be inefficient duplicative R&D by the services. McNamara canceled numerous programs and encouraged the services to procure similar or identical aircraft. Indeed, shortly after entering office, McNamara pressured the Air Force to evaluate the Navy McDonnell F4H-1 Phantom II as an interim replacement for the Convair F-106, Republic F-105D, and McDonnell RF-101 Voodoo. After highly successful trials, the Air Force ordered a new version of the Phantom—the F-4C.[3] The rising unit costs of military aircraft and the new emphasis on greater commonality of aircraft designs among the services tended to push procurement trends toward ever smaller numbers of even more complex and expensive fighters designed to offer multirole and cross-service capabilities.[4]

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[1]See Art (1968), pp. 30–34.

[2]A counterargument is that aircraft like the XB-70 were cost-effective because they forced the Soviets to allocate their even scarcer resources to matching these technologically ambitious programs.

[3]Beginning in June 1957, McDonnell began in-house studies of various Air Force variants of the Phantom II. Never having procured a fighter developed for the Navy, the Air Force initially showed little interest in these proposals. Flight tests in 1961 and 1962, however, showed that, in several key areas, the Phantom generally outperformed—often by a considerable margin—the F-106 in the interceptor role, the F-105 in the tactical fighter role, and the RF-101 in the tactical reconnaissance role. Not surprisingly, in March 1962, the Pentagon announced that the Air Force would procure a new version of the Phantom, called the F-110, as its standard tactical fighter. In September 1962, the Pentagon standardized all military aircraft nomenclature. At this time, the F-110 became the F-4C. See Francillon (1990b), pp. 180–181.

[4]As discussed later in this chapter, much of the fighter pilot community and a variety of defense reformers rebelled against this concept in the late 1960s, in part because of the relatively poor showing in Vietnam of large, heavy multirole U.S. fighters, such as the F-4, against smaller, more

For a relatively short period in the late 1950s, many observers predicted that the introduction of tactical and strategic missiles would soon make manned combat aircraft obsolete.[5] While this belief proved to be wrong, the deployment of land-based and submarine-launched strategic ballistic missiles clearly reduced the relative importance of strategic bombers in the view of U.S. military planners of the period. Indeed, no new strategic bomber design was fully developed in either the 1960s or the 1970s. At the same time, medium bombers essentially disappeared as a distinct and separate category of aircraft, as their role was taken over by heavy multirole fighter-bombers, such as the F-4E Phantom, and tactical bombers, such as the F/FB-111.

The 1960s and 1970s witnessed shifts in the design emphasis and technology focus for new fighter aircraft designs as a result of changes in operational doctrine and other factors. The technological focus on increasing speed and altitude that dominated the 1950s disappeared in the following decade, replaced by a focus on maneuverability, maintainability, and system integration. Considered by many as the most capable fourth-generation fighter, the F-15 nonetheless boasted approximately the same empty weight, ceiling, and top speed as its immediate predecessor, the F-4. Other highly successful fourth-generation fighters, such as the F-16 and F/A-18, actually weighed less empty, had lower top speeds, and had only modestly higher ceilings than the last second- and third-generation fighters. However, many other performance characteristics, such as agility, turning capability and specific excess power, were vastly superior in the newer aircraft.

These changes came about because of the relative decline in the operational utility of ever-greater speed and ceiling and the growing cost and technical challenges of achieving them. The strategic and doctrinal shift toward limited tactical warfare implemented under President Kennedy—and lessons learned from air combat experience in the early years of the Vietnam War, during the Indo-Pakistan War of 1965, the 1967 Arab-Israeli War, and later Middle East engagements—led to a new design and technological focus for fighters. These emphasized maneuverability, agility, and advanced avionics. Air combat in

agile Soviet designs, such as the MiG 21. The F-15 and F-16 were subsequently designed as dedicated single-role air combat fighters. But the same cost trends discussed here, combined with a variety of other factors, led the F-16 to evolve toward a heavier multirole fighter during development, and even the F-15 program eventually produced multirole attack versions.

[5]Bright (1978), pp. 18–19. In Great Britain, the government issued a Defence White Paper in April 1957 that stunned the British aircraft industry. The White Paper reoriented British defense policy toward a heavy reliance on nuclear weapons and missiles. It called for the cancellation of all British fighter and bomber R&D programs then under way, predicting that, within 10 years, all Royal Air Force missions would be carried out by unmanned missiles and vehicles. See Gallois (1957). Although manned aircraft R&D programs continued for some years, nearly all national programs were canceled by the Labour government in the first half of the 1960s.

Photo 4.1—The McDonnell F-4 Phantom has been characterized as the most significant and successful Western fighter of the 1960s. First flown as a Navy fighter in May 1958, the F-4 was eventually procured in large numbers by the U.S. Air Force and several foreign air forces.

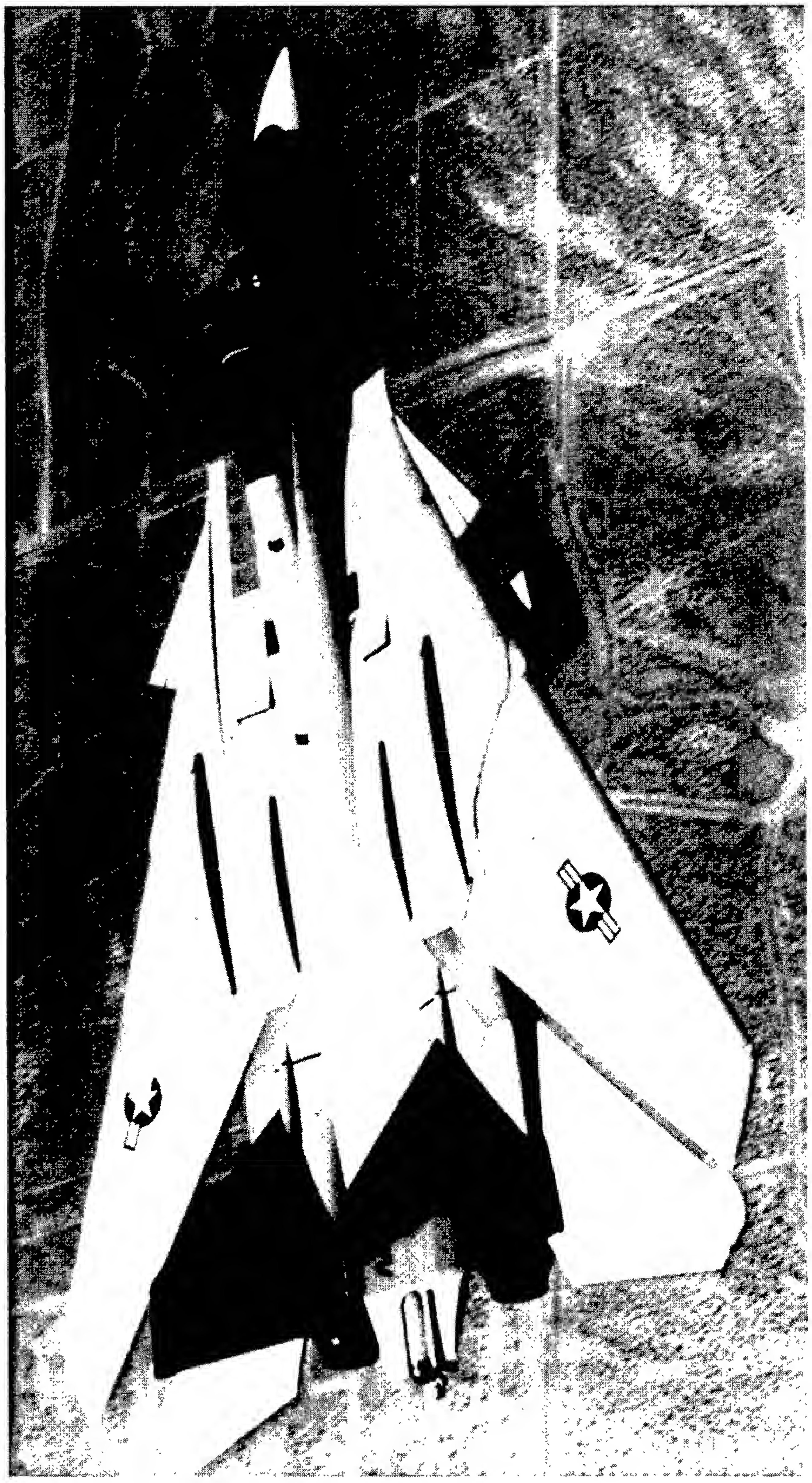

Photo 4.2—The Grumman F-14 Tomcat evolved out of the failed Grumman/General Dynamics F-111B program in the early 1970s to become the Navy's most important fleet air-defense fighter.

Vietnam and in the Middle East revealed the limitations of early generation long-range air-to-air missiles and showed the importance of maneuverability and agility in winning dogfights with guns or early generation short-range infrared (IR) missiles. The initial experience with ground-attack missions in Vietnam indicated that fighter-bombers were vulnerable to surface-to-air missiles and other ground-based air defenses and were unable to deliver ordnance with the required accuracy against ground targets. As a result, designers and engineers concentrated on increasing maneuverability for air combat success and developing and integrating the avionics necessary to counter enemy threats and to deliver munitions more accurately and effectively. While proponents of lighter, more agile dogfighters hoped to bring down escalating costs, the need for more-sophisticated avionics and other complex subsystems meant that, in the end, the cost trends continued upward.

As a result of these cost, technology, and procurement trends, the 1960s and 1970s witnessed a significant decline in the number of new military manned aircraft R&D programs from that of the 1950s. By one accounting, the number of military aircraft designs that were developed and reached first flight during the 1960s fell by around two-thirds from the previous decade. The numbers declined even further in the 1970s.[6] Figure 4.1 shows some of the major fixed-wing, missile, and space projects of this period.

These trends are clearly reflected in the narrower area of fighter R&D. During this second period, the feverish pace of fighter R&D evident in the 1940s and 1950s slowed considerably. Only two new Air Force and two Navy tactical fighters entered full-scale development—the F-15, F-16, F-14, and F/A-18. One tactical fighter-bomber also completed development—the F-111—but this large, heavy attack aircraft could hardly be considered an air-superiority fighter in the usual sense of the term. As a result, the field of leading fighter contractors shrank considerably, as more companies withdrew from the market. No new entrants came into the arena, not only because of the shrinking number of new programs, but also because the slower rate of overall technological change during the period provided fewer openings for new firms. Therefore, compared to the 1945–1961 period, the relative importance of special firm-specific knowledge relevant to fighter R&D appears to have declined.

System-specific experience appears to have risen in importance during the 1960s and 1970s, as many of the historic leaders in fighter R&D continued to excel. McDonnell-Douglas[7] raised itself to a position of world leadership in

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[6]See Drezner et al. (1992), pp. 29, 49. According to our data, there were 122 R&D programs for manned military aircraft in the 1950s, compared with 39 such programs in the 1960s and 1970s.

[7]The McDonnell Company merged with the Douglas Aircraft Company in January 1967.

RAND MR939-4.1

		1960	1965	1970	1975
Boeing	(M)	C-135*		E-3 (AWACS)	AGM-86 (ALCM)
	(C)	727	737 747 SST		757 767
GD	(M)	**F-111**** **RB-57F**		**YF-16**	**F-16** **CCV F-16** BGM-109A/B, G (SLCM/GLCM)
	(C)		600-640		
Grumman	(M)	**A-6*** **F-111B*** E-2* C-2 **E-A6A**	**E-A6B**	**F-14**	
Lockheed	(M)	P-3* **YF-12A** **SR-71** **A-12*** C-141 D-21	C-5	S-3	**XST** **F-117**
	(C)			L-1011	
McDonnell	(M)	**F-4***	KC-10	**F-15**	**F/A-18**** **AV-8B**
	(C)	DC-9	DC-10		MD-80
Northrop	(M)	X-21 **F-5A/B**		**F-5E** **YA-9A** **YF-17**	**F/A-18**** **F-20**
Republic	(M)			**YA-10** **A-10**	
	(C)		Merlin & Metro F-228		
Rockwell	(M)		OV-10A	**B-1A** **XFV-12A**	HiMat
	(C)		Aero & Lark	Sabre & Aero 112	
Vought	(M)		**A-7**		

*Program began in the late 1950s. **Cooperative program with another contractor.

SOURCE: RAND database.

(M) = military; (C) = commercial; bold = fighters, bombers, and related programs; underlined = missiles; normal = X-planes, commercial aircraft, and miscellaneous.

NOTE: Aircraft placement approximates beginning of full-scale development. Some programs are not included in the database because of a lack of precise development dates.

Figure 4.1—Selected Major Fixed-Wing and Cruise Missile Programs, 1960–1980

tactical fighter R&D through the enormous success of the F-4 in both the Navy and Air Force inventories, followed by victory in both the Air Force F-15 and the Navy F/A-18 competitions (the latter with Northrop), as well as the AV-8B Harrier.[8] General Dynamics (formerly Convair),[9] remained a prominent Air Force developer by winning the F-16 R&D contract, as well as the F-111 fighter-bomber. Grumman maintained its dominant position in Naval tactical fighters by working on the F-111B development program and by developing the F-14.

However, at least three prominent leaders from the 1940s and 1950s were shut out of the mainstream fighter market during this period. Republic, North American, and Lockheed failed to win major fighter contracts and appeared to have permanently lost their historic positions as important Air Force fighter developers. On the Navy side, the number of dedicated fighter developers shrank to one: Grumman.[10] Douglas had already effectively withdrawn from the fighter market well before the merger with McDonnell. After its success winning the A-7 development contract, Vought, now LTV, failed to garner new fighter R&D programs.[11]

Despite this attrition, the remaining leading fighter R&D companies—McDonnell-Douglas, General Dynamics, and Grumman—were among those that had pioneered the development of jet fighters after World War II and possessed vast system-specific experience.

MCNAMARA AND THE TFX: ONE SIZE FITS ALL

The Tactical Fighter Experimental (TFX—later the F-111) program, as modified by the incoming Kennedy administration in 1961, not only clearly marks the beginning of the second era in the postwar history of fighter and bomber development, but also conveniently illustrates many of the issues in fighter R&D that dominated the entire era.

With the cancellation of the F-103, F-107, and F-108 in the late 1950s and the downgrading of the XB-70 bomber to a technology-demonstrator project, many contractors anxiously looked forward to three new anticipated R&D programs for a future Air Force tactical fighter-bomber to replace the F-105, a Navy fleet

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[8]A development of the British Aerospace Harrier.

[9]Electric Boat and Canadair merged in 1952, forming General Dynamics. In 1954, General Dynamics acquired Convair. However, the main Ft. Worth facility was still routinely referred to as Convair until the early 1960s.

[10]McDonnell-Douglas, of course, remained a leading developer of Navy fighter and other combat aircraft but became increasingly involved in the development of fighters for the Air Force.

[11]In 1961 Chance-Vought merged with other companies to form Ling-Temco-Vought, later called LTV. Aerospace industry observers, however, often continued to refer to LTV as Vought.

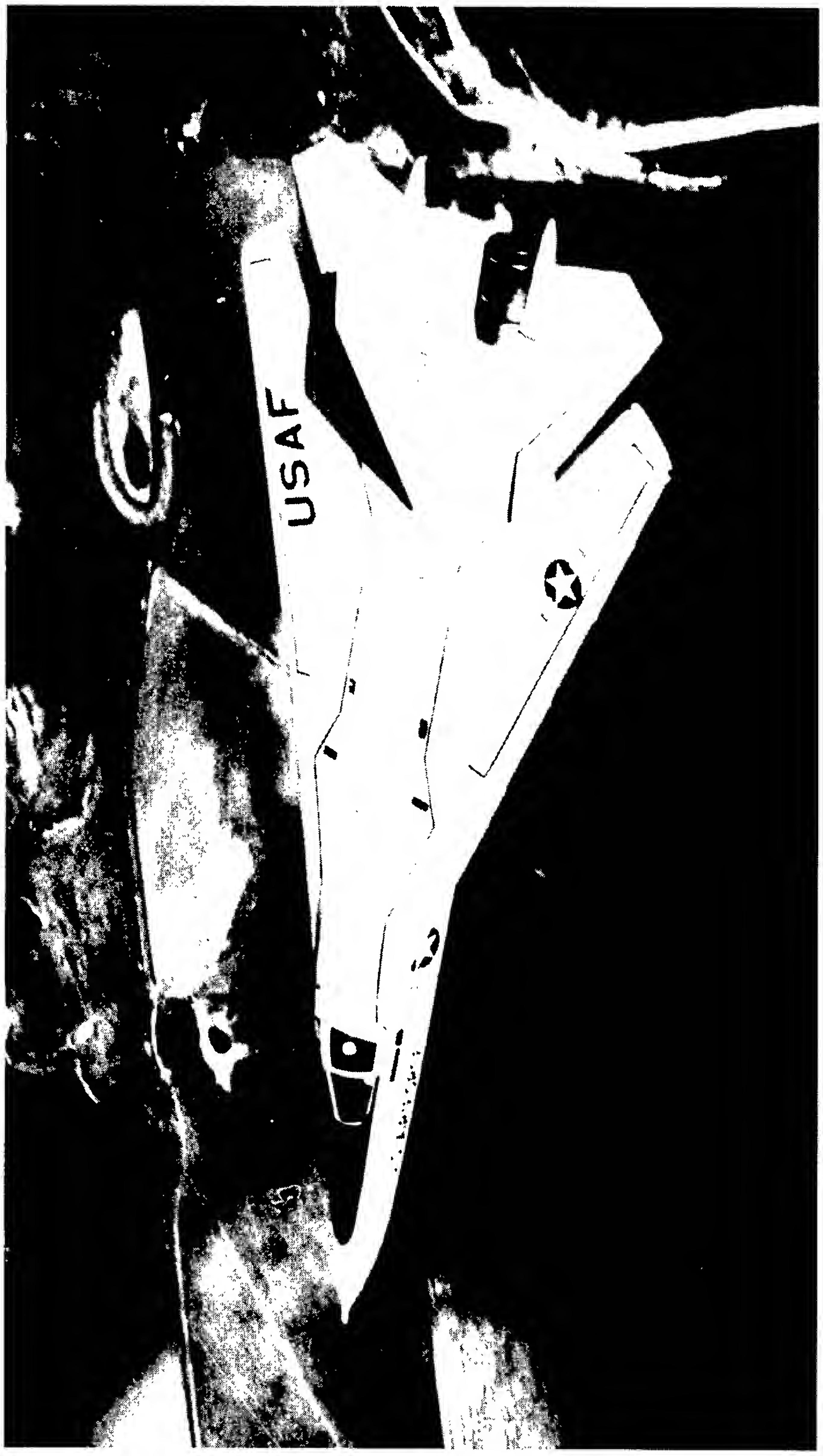

Photo 4.3—The General Dynamics F-111 caused considerable controversy in the early 1960s but eventually became a valuable attack asset in the U.S. Air Force inventory.

interceptor, and a close air support combat aircraft. Following the election of President Kennedy, however, Secretary McNamara quickly shattered these expectations. To the great consternation of both contractors and the services, the new Secretary of Defense sought to achieve added procurement efficiencies by combining these replacement requirements—minus close air support—into a single aircraft. Many industry and service officials objected vigorously to this approach, arguing that a single aircraft could not adequately satisfy the performance requirements for both types of missions. Ignoring these criticisms, McNamara forged ahead with his new quest for greater equipment commonality, as reflected in the TFX Request for Proposals (RFP) issued in September 1961. Calling for a 60,000-lb. gross takeoff weight and low-level supersonic dash capability for the delivery of nuclear and conventional weapons, the TFX requirement asked for a large multirole fighter-bomber in the same weight class as medium bombers, such as the B-57 and B-66.[12]

McNamara began pressuring the Air Force to procure the existing Navy McDonnell F-4 as an interim tactical fighter pending deployment of the TFX/F-111, expected the Navy to procure the F-111B version as its new fighter, and dramatically cut back on the XB-70 and B-58 bomber programs. As a result, the TFX rapidly emerged as the only major new program on the horizon for both fighter and bomber developers. In this new environment of declining new program starts, nearly all combat aircraft developers entered the TFX competition and fought extremely hard to win the contract. All the leading Air Force fighter developers submitted serious proposals, including General Dynamics, North American, Lockheed, and Republic, as did the leading Navy fighter developers, including Grumman, McDonnell, Douglas, and Chance-Vought. The bomber developers were there too. Having failed to win either the B-58 or the XB-70 strategic bomber competitions in the 1950s, Boeing was determined to win the TFX competition. The Seattle firm, along with many of the other contractors, realized that losing the TFX could lead to an involuntary exit from the combat aircraft industry.

To the surprise of many observers, the Air Force Selection Board and Navy representatives initially selected the Boeing design in January 1962, but the Air Force Council later rejected it. Boeing and the runner-up—General Dynamics, which had teamed with Grumman—then received follow-on study contracts. In June, the Air Force once again selected the Boeing proposal, but the Navy refused to approve it. Refined proposals were received in September, and once again the Air Force selected the Boeing design. To Boeing's great consterna-

[12]See Knaack (1978), pp. 223–224.

tion, however, McNamara overturned the decision of the uniformed services and gave the contract to General Dynamics.[13]

The Defense Secretary's decision caused a huge political scandal. Since General Dynamics was based at Ft. Worth, in the home state of Vice President Johnson, and was in serious financial trouble because of the major cutback in the B-58 program decided in December 1960, many observers thought the General Dynamics design had been selected over a superior Boeing design merely to save the Ft. Worth company from going out of business. Extensive congressional hearings were held on this issue, but no definitive conclusions were reached.

For our purposes, the most interesting information to come out of the hearings was the evidence of the technical strengths and weaknesses of the two proposals and a nonpolitical rationale explaining McNamara's decision. Testimony suggested that three key factors behind the secretary's decision were that the General Dynamics proposal showed more commonality between its Air Force and Navy versions, that the Texas firm's technical approach was more conservative and credible, and that General Dynamics' cost estimates appeared more reliable and believable. The second two factors appear to be a reflection of General Dynamics' far greater experience in the development of high-performance, supersonic combat aircraft. Although Boeing's design promised slightly greater performance on paper, General Dynamics' proposal—in the view of the Office of the Secretary of Defense (OSD) and many Air Force engineers—showed a much more realistic appreciation of the realities of supersonic combat aircraft development. Indeed, analysis of the two proposals suggested that only General Dynamics' design would be capable of sustained low-level supersonic dash. OSD engineers considered Boeing's use of top-mounted engine air inlets and maneuvering thrust reversers on its design to be particularly unrealistic on a Mach-2 fighter-bomber. Thus, according to extensive Department of Defense (DoD) testimony, General Dynamics won the contract because its design and its prospects for successfully developing it were indeed superior to Boeing's.[14]

This outcome is hardly surprising from the perspective of system-specific experience. By 1960, General Dynamics had accumulated a wealth of system-specific experience with supersonic combat aircraft unmatched by nearly any other contractor. With its F-102 and F-106 fighter development programs and its B-58 strategic bomber R&D effort in the 1950s, General Dynamics could be considered, along with North American, as the premier developer of USAF

[13]Knaack (1978), p. 225.

[14]Coulam (1977); Art (1968).

supersonic combat aircraft at the time. Boeing, on the other hand, had never developed any supersonic jet fighter or bomber whatsoever and had not developed a military aircraft of any type since the early 1950s.

Finally, General Dynamics was teamed with Grumman. Although Boeing had begun design studies on variable-geometry swing wings of the type to be used on the F-111 considerably earlier than had General Dynamics, Grumman had actually designed, developed, and flight tested a variable-geometry fighter prototype in the 1950s, the F10F. Grumman, of course, stood out as the historic industry leader in Navy fighter aircraft development. In short, it is certainly arguable that General Dynamics and Grumman won the competition because of their greater technical realism based on extensive experience in development of supersonic combat aircraft.[15]

Winning the F-111 contract assured General Dynamics a continuing role as a leader in the development of Air Force fighters and bombers. Air Force adoption of the F-4 Phantom around the same time catapulted McDonnell into the position of America's leading manufacturer of tactical fighters. The other leading fighter developers, however, seemed to be confronted with grim prospects. Although Grumman had won the lead position for the Navy version of the TFX—the F-111B—the New York firm was clearly subordinate to General Dynamics on the program. Far worse were the consequences of the TFX program for the other traditional leading Air Force fighter developers—Republic, North American, and Lockheed—as well as the Navy fighter developers Douglas and Vought.

Failure to win the TFX competition effectively ended the hopes of both Republic and Douglas to remain viable developers of fighter aircraft. Since the 1930s, Republic had specialized almost exclusively in developing large, heavy fighter-attack aircraft for the Air Force. With F-105 production ending in 1964 and General Dynamics selected as the developer of the follow-on to the Thunderchief, Republic appeared to have been squeezed out of its specialty market. The company won a reprieve in 1965 when it was purchased by Fairchild Corporation. Hopes for reentry into the fighter market soared briefly when Fairchild-Republic won a contract in 1966 for a new Air Force vertical takeoff and landing (V/TOL) fighter to be developed collaboratively with Germany. However, Secretary McNamara canceled the project in early 1968, once again leaving Republic with no aircraft contracts.[16]

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[15]Indeed, General Dynamics was well aware of the unhappy consequences of technological overoptimism from its F-102/106 and B-58 programs and would suffer the consequences again on the F-111. For an exhaustive discussion of these issues, see Art (1968), pp. 115–132; Coulam (1977), pp. 62–65.

[16]See Stoff (1990), pp. 166–167.

Douglas found itself in a similar position regarding fighter aircraft as a result of McNamara's policies and General Dynamics' victory in the TFX competition. In July 1960, Douglas had won a hard-fought competition to develop the Navy's ultimate stand-off air defense fighter, the F6D-1 Missileer. This fighter was envisioned to be little more than a long-endurance subsonic missile launch platform. The Missileer was intended to loiter for hours out in front of the fleet and to launch the Bendix-Grumman XAAM-N-10 Eagle long-range missile at enemy bombers more than 150 miles away. McNamara canceled this program in April 1961, however, after folding the Missileer mission into the new TFX requirement. As a result, Douglas's survival became almost entirely dependent on its commercial aircraft sales. However, problems with both the DC-8 and DC-9 airliners led to a financial crisis in 1965. The next year, McDonnell bought out the ailing Douglas corporation.[17] The Douglas division continued to design airliners, but this famous developer of the legendary carrier aircraft that won the Battle of Midway never again developed a Navy fighter or attack aircraft.[18]

North American, Lockheed, and Northrop found themselves with no prospects for a new first-line fighter program after the TFX decision, but these companies had other work to keep them busy. North American had increasingly specialized in space; high-speed test aircraft, such as the X-15; and supersonic bombers, such as the XB-70 and later the B-1A. Lockheed moved ahead vigorously in space; military and commercial transports; and specialized high-speed reconnaissance aircraft, including the spectacular Mach-3 SR-71, a version of which the Air Force briefly considered for procurement as the YF-12 fighter-interceptor. Northrop focused heavily on its highly successful lightweight export fighter, the F-5 Freedom Fighter, and the T-38 jet trainer on which it was based.

After the TFX decision, some hope lingered among these traditional Air Force fighter contractors, as well as Republic, that the Air Force requirement for a close-air support aircraft might lead to a new fighter-attack aircraft program. As the war in Vietnam began to heat up, many in the Air Force supported procurement of a version of the F-5, while others called for a specialized counterinsurgency aircraft. To the considerable consternation of the traditional Air Force contractors and many in the Air Force, McNamara once again pushed for greater service commonality by pressuring the Air Force to procure a version of the Navy Vought A-7 attack aircraft, which itself was a development of the Navy

[17]The merger between the companies was approved in January 1967.

[18]See Bright (1978), pp. 192–196. Douglas SBD Dauntless dive bombers played a central role in sinking four Japanese aircraft carriers at the decisive Battle of Midway in June 1942 and remained the most important carrier-based Navy attack aircraft of the war. Its creator, Ed Heineman, went on to design one of the most famous U.S. carrier-based attack aircraft of the jet era, the Douglas A-4 Skyhawk.

Vought F-8 Crusader. In early 1966, the Air Force agreed to procure an upgraded version of the A-7, ending once and for all the hopes of the traditional Air Force fighter contractors for a new program.[19]

Thus, by the mid-1960s, McNamara's push for greater service equipment commonality and the development of multirole fighters had produced a grim outlook for many traditional fighter developers. It appeared that all anticipated fighter and attack aircraft requirements for the Air Force and Navy would be filled by the TFX or by versions of existing aircraft. But increasing technical problems, cost growth, and schedule slippage on the TFX program, combined with growing Air Force and Navy dissatisfaction with anticipated TFX performance limitations in aerial combat, led to a dramatic turnaround of this situation in the late 1960s. In the end, new R&D efforts were launched that led to some of the most successful and capable conventional jet fighters ever developed by American industry.

[19]Gunston (1974), pp. 234–242.

Chapter Five

REVIVAL OF THE AIR-SUPERIORITY FIGHTER

INTRODUCTION

The late 1960s and 1970s witnessed the development of two new Air Force fighters—the F-15 and F-16—and two new Navy fighters—the F-14 and F/A-18—that would become the mainstays of America's tactical fighter forces for the remainder of the century. In particular, the two Air Force fighters and the F/A-18 represent a substantial change from many of the trends evident in previous fighter modernization decisions. The F-15 was the first Air Force fighter since the development of the North American F-86 in the late 1940s that was optimized for maneuverability and agility for dogfights with enemy fighters. In an even more dramatic departure from recent experience, the F-16 and F/A-18 programs attempted to reverse the trends toward heavier, more complex and costly fighters.

These changes did not come easily. They resulted from a long, arduous, and turbulent process during which various schools of thought on fighter doctrine and design vied for influence. Nonetheless, these often vitriolic debates ended in the design and development of several of the world's most capable fighters.

OF EAGLES AND TOMCATS

As early as 1964, a consensus began to emerge within the Air Force that a new tactical fighter was needed. This consensus in part reflected Air Force dissatisfaction with the TFX program and McNamara's policy of fighter commonality among the services. Under McNamara's guidance, the Air Force took the unprecedented step of procuring two Navy-developed combat aircraft, the F-4 and the A-7, and agreed to develop the F-105 replacement as the joint TFX program with the Navy. As serious developmental problems emerged on the TFX program that indicated that the F-111 would not be able to meet all of its multirole, multiservice performance requirements, various influential elements

within the Air Force increasingly voiced the desire for a tactical fighter developed by and for the Air Force.[1]

During the first half of 1965, Air Force officials continued to debate some of the fundamental issues that still caused concern on the TFX program, such as multirole ground-attack capability versus air-superiority optimization, and Air Force–Navy commonality. However, the escalation of the air war over Vietnam soon convinced many officials in the Air Force and the Pentagon that a new, specialized air-defense fighter was needed, as antiquated North Vietnamese MiG-17s began registering victories over much larger, more complex and expensive, but less maneuverable U.S. fighters. On April 4, 1965, several North Vietnamese Korean War vintage MiG-17s equipped only with guns shot down two sophisticated F-105s on a bombing run against the Than Hoa Bridge. This incident shocked the U.S. tactical fighter community and galvanized sentiment in the Air Force for a new air-superiority fighter. Shortly thereafter, General McConnell, Air Force Chief of Staff, issued a formal document emphasizing the importance of the air-superiority mission. This document served as the basis for a requirement statement for a new fighter.[2]

In November 1965, OSD directed the Air Force to procure a version of the Vought A-7 as its new dedicated attack aircraft. While disappointing to those who advocated procurement of a higher-performance supersonic fighter-attack aircraft, such as the Northrop F-5A, for the ground support mission, this decision nonetheless cleared the way for the later acquisition of a specialized air-superiority fighter. In December 1965, the DoD launched a Concept Formulation Phase for a new fighter, dubbed the F-X, by sending out RFPs soliciting parametric design studies to 13 contractors. Eight companies responded, and in March 1966, the DoD awarded study contracts to North American, Lockheed, and Boeing. Grumman also participated using its own funds.[3]

However, important elements within OSD and the Air Force remained opposed to a specialized air-defense fighter, preventing consensus from forming around any one of the design approaches the participating contractors had advanced. Many OSD officials still favored a joint Air Force–Navy multirole fighter (referred to as the F-X–Navy Fighter Attack Aircraft Experimental [VFAX] requirement) with significant ground-attack capabilities. In addition, the USAF Aeronautical Systems Division proposed a very large multirole fighter with a variable-geometry wing with a maximum takeoff gross weight of 60,000 lbs. As the F-X design evolved toward an aircraft similar to the increasingly controversial F-111 and as projected R&D costs skyrocketed, opposition within the Air

[1]Gentry (1976), pp. 9–10.

[2]Stevenson (1993), p. 73.

[3]See Francillon (1984), pp. 1–2; Gething (1983), pp. 4–5; and Francillon (1990b), pp. 298–299.

Force mounted. One group of dissenters, later known as the "Fighter Mafia," led by John Boyd, Pierre Sprey, and others, began arguing with considerable effect against such a fighter within the Air Force and the DoD. This group advocated procurement of a much lighter, highly maneuverable dogfighter optimized for close-in air combat.

The influence of this group on the highest levels of the Pentagon increased dramatically in 1966 when Boyd came to the Air Staff, Requirements, Tactical Division, and Sprey joined the acquisition staff of OSD. Boyd was an experienced fighter pilot who was the author of the air combat training manual used at the Fighter Weapons School at Nellis Air Force Base. As an engineering student at Georgia Tech in 1962, Boyd expanded and applied to fighter aircraft a mathematical theory (previously published for analysis of general aviation) relating weight, drag, thrust, and lift characteristics to maneuvering performance. Later developed into the "Energy Maneuverability Concept" with mathematician Tom Christie, this theory helped the Fighter Mafia's supporters translate their air maneuverability requirements directly into aircraft engineering design requirements. Sprey, a former operations research analyst at Grumman involved in the development of the Missileer and the F-111B concepts, strongly supported Boyd's views. In early 1967, Boyd and Sprey mounted a coordinated assault on the Aeronautical Systems Division's 60,000-lb. multirole variable-geometry fighter-bomber concept for the F-X.[4]

Throughout the first half of 1967, Boyd and Sprey conducted extensive design trade-off analyses to support their argument for a highly maneuverable, dedicated air-superiority fighter. Largely through such efforts, a smaller, more maneuverable F-X concept called Blue Bird emerged in the spring of 1967. Debate continued with no action being taken, however, until the revelation of new Soviet fighters galvanized opinion in OSD and the Air Force around the Blue Bird concept. In July 1967, at an air show at the Domodedovo airfield near Moscow, the Soviet air force revealed two new highly capable fighters: the MiG-25 Foxbat and the MiG-23 Flogger. Many officials in the Pentagon believed that these new fighters, particularly the MiG-25, would be difficult for the F-4 or other existing U.S. tactical fighters to counter. This revelation tremendously reinforced the arguments for a specialized, highly maneuverable air-superiority fighter uncompromised by multirole air-to-ground capabilities.[5]

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[4]Other leaders of the Fighter Mafia included Everest Riccioni, an experienced F-100C pilot; Charles ("Chuck") Myers, a former test pilot and Navy fighter pilot who worked for Lockheed on the development of the lightweight F-104; John Chuprun at Wright Patterson AFB; Richard Willis at Nellis AFB; and Al Price at the Air Force Academy. The account presented here draws on a variety of open sources, as well as on interviews the principal author conducted with Boyd, October 8, 1980; Christie, September 19, 1980; Myers, September 24, 1980; and Sprey, September 19, 1980.

[5]Ironically, neither of the two new Soviet fighters proved to be outstanding dogfighters, particularly the MiG-25, which allegedly had been developed to counter the Mach 3 XB-70 strategic bomber.

In response to these and other factors, the Air Force sent out a new RFP in August to seven contractors for a new round of design studies. In December 1967, the Air Force awarded study contracts to the two winning firms: McDonnell-Douglas and General Dynamics. Three other historic Air Force fighter R&D leaders—North American, Lockheed, and Fairchild-Republic—as well as Grumman, also took part in the design study using their own corporate funds. Although considerable debate still existed within the Air Force over design configuration, weight, and multirole capabilities for the F-X, most Air Force officials now supported an air-superiority fighter and strongly opposed compromising the capabilities of the future F-X by requiring it to fulfill carrier-based Navy or ground-attack missions.

Indeed, with the unhappy experience of the TFX continuing to unfold, both Navy and Air Force resistance continued to grow to OSD's concept of a joint F-X/VFAX program. As the Air Force struggled to hammer out a consensus on performance requirements for an all–Air Force F-X, the Navy tactical fighter community, allied with Grumman, increasingly sought to cancel the F-111B program and replace it with a new R&D effort for an all-Navy fighter optimized for fleet air defense and uncompromised by requirements for the Air Force strike-attack or air-superiority missions.[6]

Like Pierre Sprey, many pilots in the Navy tactical fighter community had been ambivalent from the very beginning about the stand-off "Missileer" concept of fleet air defense that had been passed on from the canceled Douglas F6D-1 to the F-111B. Even fewer in the Navy favored the joint Navy–Air Force development of the TFX as a replacement for the canceled Missileer. These concerns increased as developmental problems and performance shortcomings began to emerge on the Navy F-111B program. Shortly after flight testing of the F-111B prototype began in May 1965, two serious problems soon became evident: excessive weight growth, and compressor stalls caused by the engine inlet design. Other problems included poor pilot visibility on approach to carrier landings. Extensive measures were taken to try to resolve these problems, including moving the landing gear aft and development of a new nose and a higher-thrust engine. Grumman initiated two major weight-reduction programs.[7]

Insurmountable opposition in the Navy to continuing the F-111B finally emerged in response to the same event that crystallized Air Force support for an

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Nonetheless, the F-4 did not have the altitude and speed capabilities to deal effectively with the MiG-25.

[6]The following account is drawn from Coulam (1977), Stevenson (1975), and Art (1968).

[7]With a touch of humor, Grumman called these programs SWIP for Super Weight Improvement Program and CWIP for Colossal Weight Improvement Program.

F-X optimized for air superiority: the revelation of new Soviet fighters at the Moscow Air Show in July 1967. The existence of new-generation Russian fighters, combined with the renewed appreciation for the importance of maneuverability and dogfighting gained from air combat experience over Vietnam, led the Navy to argue convincingly for the need for a specialized Navy fighter optimized for carrier-based fleet air defense. The Navy soon awarded a contract to Grumman for a study evaluating the F-111B's capabilities in combat against the new Soviet fighters. In October, Grumman reported that the F-111B would not be able to cope with the new Russian fighters in a dogfight. More importantly, Grumman submitted an unsolicited design proposal, based on company design studies under way since 1966, for a totally new fighter that could meet the Navy's fleet air-defense needs.[8] Shortly thereafter, two other historic Navy fighter developers—LTV (Vought) and McDonnell-Douglas—also submitted design proposals, as did a seasoned Air Force fighter developer, North American Rockwell.[9] All these companies, with the exception of LTV, were also active participants in the Air Force F-X design studies. At around the same time, the Navy informed General Dynamics that the F-111B did not meet its requirements and initiated a new study of alternatives.

The Navy campaign to cancel the F-111B and develop its own fighter gained momentum at the end of 1967 when OSD appointed the Air Force as the executive agent for the development of a single new engine for a joint F-X/VFAX. By this time, both the Navy and Air Force were fully committed to developing their own fighters uncompromised by mission requirements from the other service, and the Navy now saw the Air Force as getting the upper hand in the OSD-supported F-X/VFAX program. The Navy campaign finally succeeded six months later in July 1968 when Congress agreed to terminate the F-111B program. That same month, the Navy sent out RFPs to industry for a new VFX fighter, developed solely under Navy auspices and optimized for the fleet air-defense mission. In addition to Grumman, North American, LTV, and McDonnell-Douglas, General Dynamics also submitted design proposals.

As noted earlier, by late 1967 when Navy officials had ratcheted up their campaign to cancel the F-111B, the lighter, more maneuverable Blue Bird F-X had gained widespread acceptance in the Air Force. At this time, however, Boyd, Sprey, and other members of the Fighter Mafia intensified their efforts to influence the F-X configuration toward an even smaller, less complicated, more maneuverable LWF. By the spring of 1968, they had formulated a new "Red Bird" F-X concept, which called for a lower-cost, even lighter fighter with lower

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[8]However, Grumman proposed retention of a swing-wing design and many F-111B systems, such as the engines.

[9]In 1967, North American merged with Rockwell Standard to become North American Rockwell.

wing loading, fixed inlets, a low-bypass turbofan, and less-complex avionics. Some elements within the Air Force strongly supported Red Bird as a means of procuring larger numbers of fighters because of its lower procurement costs, but the same views that had undermined the F-104 program and prevented procurement of the F-5 remained prevalent. Furthermore, following the cancellation of the F-111B in mid-1968, Air Force officials realized that a rapid consensus had to be achieved on F-X to discourage OSD from folding the F-X requirement into the Navy VFX RFP. By the fall of 1968, Air Force consensus had essentially been achieved on the Blue Bird F-X concept with fixed wings.[10] Although the Red Bird advocates were forced to admit defeat for the time being, they clearly had been instrumental in preventing approval of a heavy multirole F-X concept similar to the TFX/F-111.[11]

On September 30, 1968, the Air Force sent out a new F-X RFP based on the Blue Bird concept to eight prime contractors. Only four companies responded with serious proposals. Not surprisingly, these were General Dynamics, North American, and Fairchild-Republic—the three historic Air Force fighter developers—and McDonnell-Douglas—the emerging U.S. industry leader in fighter R&D. After eliminating General Dynamics from the competition, the Air Force awarded contracts for a six-month project-definition phase to the remaining three contractors on December 30, 1968. In an apparent confirmation of service displeasure with the entire TFX affair, the Navy also eliminated General Dynamics from the VFX competition the same month, along with LTV and North American, leaving Grumman and McDonnell-Douglas as finalists.

This decision presented McDonnell-Douglas with a chance to win both the F-X and VFX competitions, thereby reinforcing the already dominant biservice position it had won through the F-4 program. On the other hand, Grumman, North American, and Republic all found themselves in "must-win" situations. If they did not win their respective competitions, they could not expect to remain leaders in high-performance tactical fighter R&D. Indeed, LTV's elimination from the VFX competition essentially meant the end of its history as a prime contractor for Navy fighters.

The VFX competition concluded rapidly. In mid-January 1969, the Navy selected Grumman to develop the VFX, later designated the F-14A Tomcat. Observers widely anticipated Grumman's selection for several reasons. First and foremost, Grumman remained the historic leader in Navy tactical fighter development and had continued to gain additional experience on the F-111B

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[10]Variable-geometry variants had also been examined.

[11]Francillon (1984), p. 2.

Photo 5.1—The Lockheed (formerly General Dynamics) F-16 Fighting Falcon became the most numerous fighter in the U.S. Air Force inventory in the 1980s and 1990s. This highly successful fighter has evolved through many variants and has remained one of the world's most effective combat aircraft.

Photo 5.2—The McDonnell-Douglas F-15C Eagle, first flown in July 1972, remained the premier air-superiority fighter in the U.S. Air Force inventory throughout the 1980s and 1990s.

program. Second, to convince OSD to support the VFX program, the Navy had argued that the new fighter would save money by drawing on subsystems, technology, design lessons, and other aspects of the floundering F-111B program. As the lead contractor of the F-111B, Grumman was much better positioned to support this approach than was McDonnell. For example, officials expected the VFX to use the same engines as the F-111. Grumman had already expended several years on design studies for the VFX air inlets and engine nozzles to avoid the engine performance and stall problems encountered on the F-111. In another example, Grumman developed a concept for a welded titanium wing box to avoid the weight growth and performance problems encountered on the bolted metal variable-geometry wing box for the F-111.[12]

The F-X competition took somewhat longer to resolve. In June 1969, McDonnell-Douglas, North American, and Fairchild-Republic submitted their final design proposals for the F-X, now designated the F-15. After six months of extensive Air Force and OSD evaluations, the secretary of the Air Force announced on December 23, 1969, the selection of McDonnell-Douglas to develop the F-15. Unlike the F-111 contest, no significant disagreements emerged within the government regarding selection of a winner. Nearly all published accounts agree that the McDonnell-Douglas design submission won on technical merit.

According to some sources, a major factor contributing to the success of the St. Louis company's design was its recent experience in developing the F-4 and other high-performance fighters intended for deployment aboard carriers. Because of its design studies for the VFX and other factors, McDonnell-Douglas rejected a variable-geometry wing for the F-15 as too complex, expensive, and heavy. But the St. Louis company, along with the other two finalists, suffered from a lack of aerodynamic data for evaluating various fixed-wing planforms optimized for high maneuverability and agility. Neither NASA nor the leading contractors had done studies on such wings since the early 1950s. All three F-X competitors conducted hundreds of hours of wind-tunnel testing in hopes of developing the best design configuration. North American eventually developed a blended wing configuration similar to that General Dynamics developed for the YF-16 in the early 1970s. Republic, drawing on its experience with the F-105 in Vietnam, came up with a design featuring widely separated engine nacelles for greater survivability. McDonnell-Douglas's design, however, benefited from the company's long experience at developing high-performance fighters that required low approach speeds at high angles of attack for carrier landings. The capability to perform at high angles of attack was a critical factor in fighter maneuverability and agility, but few wind-tunnel data existed in this

[12]Stevenson (1975), pp. 16–18.

area. McDonnell-Douglas's experience in this area helped immensely during its evaluation of over 800 wing designs and variations.[13]

On the whole, the F-15 and F-14 fighters proved to be extremely successful, although the Tomcat R&D program experienced considerable controversy in the early 1970s because of high costs and other factors. First delivered to the Air Force in November 1974, the F-15 Eagle rapidly became viewed as the premier air-superiority fighter in the Air Force inventory. In early 1984, the Air Force selected an extensively modified version called the F-15E Strike Eagle for the all-weather deep-attack mission to complement the aging F-111. By the mid-1990s, well over two decades after the F-15's initial entry into service, most observers still considered the Eagle to be the most capable air-superiority fighter in the world. Benefiting from a major upgrade program in the 1990s, the F-14 also continued on in Navy service and remained the world's premier carrier-based fighter. The F-14 program confirmed Grumman's position as the leader for more than four decades in Navy fighter R&D, while the F-15 effort indisputably established McDonnell-Douglas as America's foremost developer of USAF fighter aircraft during Period 2.

THE F-16 AND F/A-18: LIGHTER, LOWER-COST ADDITIONS

Despite the great success that the F-14 and F-15 eventually enjoyed, concerns continued to mount during the R&D programs for these fighters that the unchecked growth in fighter R&D and procurement costs could not be sustained. Many observers believed that growing costs would inevitably lead to dramatic cuts in planned procurement numbers, which in turn would result in a dangerous decline in the overall size and capabilities of the force structure. Some Pentagon officials began advocating development of cheaper, lightweight, less capable fighters that could be procured in larger numbers. Combined with the F-14 and F-15, these fighters would produce a larger force structure composed of a "high-low" mix of capabilities. At the same time, the Fighter Mafia, led by Boyd and Sprey, which had always argued that the F-14 and F-15 "Blue Bird" were too large and complex, continued to argue effectively for procurement of cheaper LWFs.[14]

With the start of the Nixon administration in 1969, Secretary of Defense Melvin Laird and Deputy Secretary of Defense David Packard initiated a wide-ranging

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[13]See Ethell (1981), pp. 15-17; Stevenson (1978), pp. 14-16; and Delusach (1970).

[14]Boyd and most of the rest of the Fighter Mafia did not, however, accept the assumption that lighter and simpler meant less capable. They argued that complicated, expensive modern fighters did not work well in real combat situations and had poor reliability and maintenance records. Larger numbers of simpler, more agile, more robust, and more reliable fighters, they argued, would actually provide greater overall combat capability for the total force structure.

review of Pentagon acquisition policy. Packard rapidly gravitated toward several major acquisition reforms that RAND and others had advocated since the early McNamara years, including design-to-cost, competitive prototyping, and fly-before-buy concepts.[15]

Packard's newfound enthusiasm for prototyping led him on a quest for suitable candidate systems from all the services. The deputy secretary particularly favored an LWF as a prototype candidate because of growing cost problems with new fighters. In 1970, the Navy F-14 fighter R&D program began experiencing severe cost-growth problems.[16] By mid-1971, Packard had slashed the anticipated F-14 buy in half and indefinitely postponed the procurement of the F-14B version with higher-thrust and improved engines. At the same time, the F-15 program was progressing well, the aircraft would clearly be expensive.

Even though the Air Force leadership had reached a consensus on the F-15 requirement in mid-1968 based on the Blue Bird F-X concept, the Fighter Mafia had continued to refine their Red Bird concept for a lighter-weight fighter. These studies led to an even lighter, simpler, more maneuverable fighter proposal dubbed the F-XX. General Dynamics and Northrop—the latter company a strong advocate of the LWF concept since the early 1950s—conducted extensive design trade-off studies on the F-XX proposal. LWF advocates within the Navy also began promoting a small, austere fighter concept labeled the VFXX as a backup if the F-14 program problems worsened. Soon contractors began more actively trying to exploit these trends. During discussions with the secretary of the Air Force in late 1970, Lockheed officials proposed development of a low-cost LWF, the CL-1200, derived from the original F-104 design. Word of this action set off a flood of unsolicited design proposals from other contractors for LWF prototypes. In the first six months of 1971, Northrop, Boeing, and LTV followed Lockheed with serious LWF design proposals. Lockheed, LTV, and North American also began LWF design studies for a Navy VFXX.[17]

Throughout the first half of 1971, Deputy Secretary Packard and other Pentagon officials became increasingly convinced of the potential benefits of funding a relatively low-cost program for the competitive development and fly-off of LWF prototypes. Such a program not only would provide a candidate LWF prototype to supplement the F-14 and F-15 if desired, but also could serve as a means of evaluating a variety of proposed acquisition reforms, such as competitive proto-

[15]Many of these reforms involved proof testing of actual hardware before major decisions were made and thus differed dramatically from McNamara's systems analysis approach and "paper competitions." See Rich et al. (1986).

[16]This cost-growth was largely attributable to Grumman's unrealistically low cost estimates during the final design competition with McDonnell-Douglas. See Sponsler et al. (1973), p. 29.

[17]Stevenson (1993), pp. 101–104.

typing and performance-based requirements. In January 1972, RFPs for an LWF prototype were sent out to nine contractors. Only the five companies that had been involved in earlier LWF design studies responded: Boeing, General Dynamics, Northrop, LTV, and Lockheed. There is some dispute in the open literature over the ranking that emerged from the technical evaluation of the designs these companies submitted. However, several sources suggest that government officials considered the designs of Boeing, General Dynamics, and Northrop to be clearly superior and roughly comparable. On April 13, 1972, the government awarded contracts to General Dynamics and Northrop to develop their prototype LWFs for a flight-demonstration program. In practice, this evolved into an intensely competitive fly-off between the two technology demonstrators for an FSD contract, although officially it remained a technology demonstration program.

The outcome of the design competition surprised few observers. General Dynamics and Northrop had been working closely with the Fighter Mafia, conducting design studies for an LWF since the earliest days of the Red Bird concept and F-XX. General Dynamics drew heavily on these years of design studies, as well as on its extensive experience gained developing the F-111 and its earlier fighters. General Dynamics' model 401 cleverly blended together for the first time a variety of cutting-edge technologies and concepts, including a variable-camber, blended-body configuration and an FBW flight-control system to optimize maneuverability and agility while controlling cost. General Dynamics' ability to develop such an impressive design clearly stemmed in large part from its years of fighter R&D experience and LWF design studies.[18]

Northrop's winning P600 design proposal emerged from a long line of earlier Northrop LWF design concepts. Northrop had been working on LWF designs for nearly 20 years, beginning with its N-102 Fang, the forerunner of its T-38 trainer and F-5A export fighter. In 1970, the Pentagon awarded Northrop a development contract for a new International Fighter Aircraft. Northrop had won out over Lockheed, McDonnell-Douglas, and LTV designs with a modified and upgraded version of its lightweight Freedom Fighter, later designated the F-5E. The all-new Northrop P530 Cobra LWF design emerged from extensive studies conducted almost continuously since 1965 to develop a follow-on to the F-5. The P600 design the Pentagon selected for the LWF fly-off with General Dynamics was a refinement of the P530.[19]

[18]Stevenson (1993), pp. 145–148.

[19]See Anderson (1976). Also in 1970, Northrop and Fairchild-Republic had won the Pentagon's A-X competition to develop prototypes of a relatively simple, low-cost attack aircraft for a competitive fly-off. In January 1973, the Pentagon selected Republic's YA-10 prototype over the Northrop YA-9 for full-scale development.

Although Lockheed had also been a pioneer of LWF development, its CL-1200 Lancer design proposal suffered from several perceived disadvantages. First, many did not view it as a new design but as only a modification of the earlier F-104, a design that had not achieved widespread support in the Air Force. Second, the CL-1200 clearly had been marketed for several years prior to the LWF competition as an export fighter, as was the F-5, as a replacement for F-104Gs in European air forces. Furthermore, Lockheed had not developed a conventional mainstream tactical fighter for nearly 20 years; many observers were unfamiliar with its superlative "black" programs, such as the SR-71. Boeing suffered even more from the perception of lack of experience. During the design evaluation, Secretary of the Air Force Seamans allegedly pointed out that "Boeing had not ever fired an afterburner in anger."[20] Lockheed designer Kelly Johnson agreed, allegedly pointing out in his journal that Boeing "had never built a modern fighter, lit an afterburner or had a supersonic airplane."[21]

Both LWF prototypes first flew in 1974. Throughout the last half of the year, military and civilian test pilots flew the General Dynamics and Northrop prototypes—now designated YF-16 and YF-17, respectively—in an intensely competitive fly-off. In January 1975, the secretary of the Air Force announced that General Dynamics' YF-16 had been selected for full-scale development. The resulting F-16 Fighting Falcon went on to become the most numerous fighter in the Air Force inventory and one of the most widely exported fighters of the last several decades. However, the F-16 quickly evolved away from the early LWF concept the Fighter Mafia had envisioned in the 1960s, as it developed into a much heavier, much more capable multirole fighter-bomber.[22]

In 1975, most observers assumed that, in accordance with the wishes of Congress, the Navy would procure a navalized version of the YF-16 to supplement the F-14. Yet the Navy was unhappy with both the YF-16, as selected by the Air Force, and the YF-17. Both aircraft clearly had to be modified considerably to be made suitable for use aboard aircraft carriers. Furthermore, the Navy wanted an attack fighter, not a lightweight dogfighter, in part because it wanted to reserve the fleet air-defense mission for the F-14.

[20]Stevenson (1993), p. 144.

[21]From Kelly Johnson's personal log dated January 6, 1972, as quoted in Stevenson (1993), p. 143.

[22]It has been claimed that the F-16 gained a pound of weight for every day that passed since its first flight. The early Block 5, 10, and 15 versions are close to the original Fighter Mafia concept of an austere, daylight dogfighter. The Block 25 and 30 versions were essentially developed as replacements for the multirole F-4 fighter-attack aircraft and were equipped for long-range, radar-guided missile capability. The Block 40 has an enhanced air-to-ground capability, which includes LANTIRN and Maverick options. The most recent and highly capable Block 50 version is an extremely versatile world-class multirole fighter bomber.

Both LWF contractors teamed with traditional Navy fighter developers to design navalized versions: General Dynamics with LTV, Northrop with McDonnell-Douglas. In May, the Navy announced the selection of the McDonnell-Douglas/Northrop team. The teaming arrangement gave leadership to McDonnell-Douglas, as an experienced Navy fighter developer, on Navy variants, and to Northrop on any land-based designs. Under the terms of the teaming arrangement, McDonnell-Douglas engineers significantly modified and redesigned the YF-17 prototype into a virtually new strike-attack naval fighter. In recognition of this fact, the aircraft was eventually designated the McDonnell-Douglas/Northrop F/A-18 Hornet.[23] The Hornet became the standard carrier fighter-attack aircraft for the Navy. In the 1990s, McDonnell-Douglas radically modified the Hornet into a new, more-capable version called the F/A-18E.

Thus, by mid-1975, McDonnell-Douglas had become the dominant contractor on two of the four major new tactical fighter R&D programs of the 1960s and 1970s. McDonnell soon further solidified its position as the U.S. leader in conventional tactical fighter-attack aircraft by launching a program for a new Marine V/STOL attack fighter. The same month that the McDonnell-Douglas/Northrop team won the F/A-18 contract, the St. Louis contractor also began studies for an advanced version of the British Aerospace AV-8A Harrier. The Pentagon approved full-scale development of this design in July 1976. Although broadly based on the British Aerospace Harrier, the new AV-8B version included newly designed composite wings, a new forward fuselage, air intakes, cockpit and front exhaust nozzles, and a lengthened rear fuselage. In short, the AV-8B amounted to a new aircraft.[24]

With McDonnell-Douglas, General Dynamics, and Grumman now almost completely dominant in recent and ongoing fighter R&D, North American Rockwell, Republic, and LTV struggled on with limited success to remain viable as recognized prime contractors for fighter development. North American Rockwell almost succeeded with a new contract in the early 1970s. In late 1971, the Navy issued RFPs for a new shipborne fighter-attack aircraft called the VFA V/STOL. Grumman, LTV, General Dynamics, Fairchild-Republic, North American, and Boeing all submitted serious design proposals. In March 1972, the Navy chose North American to develop the aircraft, now called the XFV-12A. The General Dynamics proposal also received follow-on funding. North American went on

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[23]According to one McDonnell-Douglas engineer, "The F/A-18 looks like the YF-17, but it is a brand new plane, aerodynamically, structurally, in all ways. It's a brand new airplane from the ground up..." Quoted in Orr (1991), pp. 51–52.

[24]Francillon (1990b), pp. 329–331.

Photo 5.3—The Northrop YF-17 competed unsuccessfully with the General Dynamics YF-16 in a fly-off in mid-1974 to become the Air Force lightweight fighter. Later, Northrop teamed with McDonnell-Douglas to develop the YF-17 into the highly successful Navy F/A-18 Hornet.

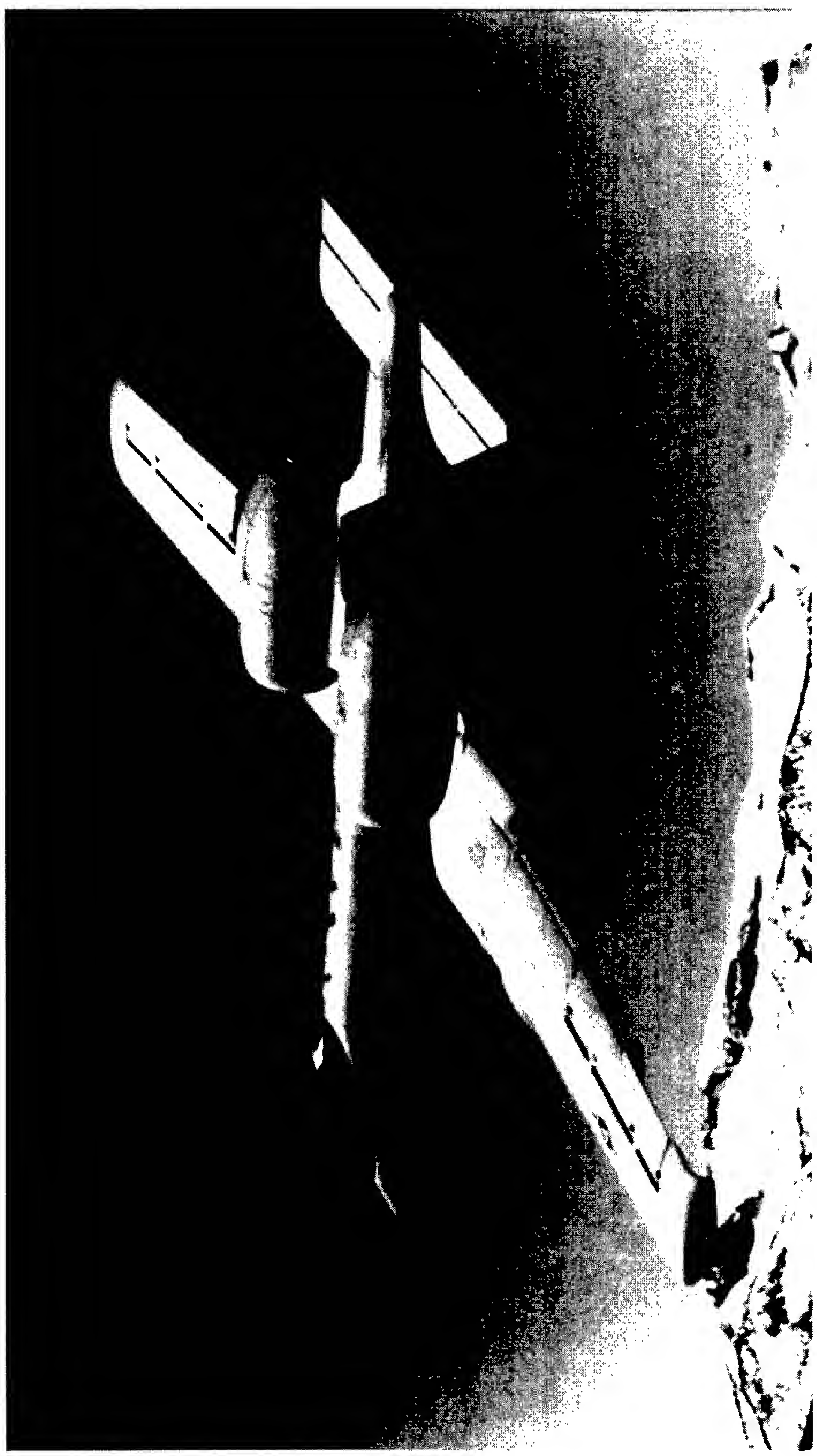


Photo 5.4—The A-10 Thunderbolt II, which first flew in May 1972, became Republic's last production combat aircraft. Selected by the Air Force after competitive flight tests with the Northrop YA-9, the Thunderbolt II proved to be a highly effective ground-attack aircraft and served with distinction during Desert Storm.

to build a technology-demonstrator aircraft, which was not successful.[25] The Navy eventually canceled the program once the AV-8B R&D effort got under way. North American also received a contract in the late 1970s to develop the Highly Maneuverable Technology (HiMAT) remotely piloted vehicle to examine supermaneuverable fighter design concepts. HiMAT contributed to the later X-31 technology-demonstrator program with Germany's Deutsche Aerospace, but this did not result in a fighter R&D effort. North American Rockwell remained a leading bomber developer and continued to build its military aircraft R&D experience through its important B-1A and B-1B strategic bomber programs.

Fairchild-Republic completed development of its A-10 Thunderbolt II attack aircraft, which had won a design and prototype competition with the Northrop YA-9. Production commenced in 1975.[26] The A-10 proved to be a lethal close-air support aircraft. Nonetheless, the ungainly but deadly A-10 was destined to be Republic's last combat aircraft. The firm won a contract in mid-1982 in competition with Rockwell, LTV, and General Dynamics to develop the T-46 trainer for the Air Force. Cost growth and technical problems led to the cancellation of the program in 1987, leading to the demise of the aviation division of Fairchild-Republic. In 1988, the site of Republic Aviation, the birthplace of the famed P-47 Thunderbolt, was sold, later to become a shopping mall.[27]

Having failed to win a fighter R&D contract since the F-8 Crusader in the 1950s or any major combat aircraft contract since the A-7 in the early 1960s, LTV evolved into a highly successful subcontractor. By the 1980s, LTV began specializing in the manufacture of large composite structures and later became a key subcontractor on important military aircraft R&D efforts.

OVERALL TRENDS IN THE 1960s AND 1970s

Most of the trends identified at the end of Chapter Three as characteristic of the first period of jet-fighter R&D were still in evidence throughout the 1960s to the mid-1970s. However, in contrast to the 1945–1961 period, two fundamental characteristics of the second period stand out above all others: continuity of leadership in fighter R&D and exits from the fighter R&D business.

The continuity of leadership in fighter R&D evident in the second period clearly shows the central importance of experience during this era. While several

[25]Stevenson (1993), pp. 148–150. The V/STOL technology did not work as well as initially anticipated.

[26]Fairchild-Republic manufactured the A-10 at the same location where it had made the original Thunderbolt of World War II fame, the P-47.

[27]Stoff (1990), pp. 183–190.

prime contractors in effect exited from the fighter business during this period, no new entrants came in to take their place. This suggests that, compared to the earlier period, the 1960s to the mid-1970s were a time of relatively less radical technological change—at least in overall engine and platform design and development. The slower pace of advance in platforms apparently enhanced the relative importance of contractors' system-specific experience.

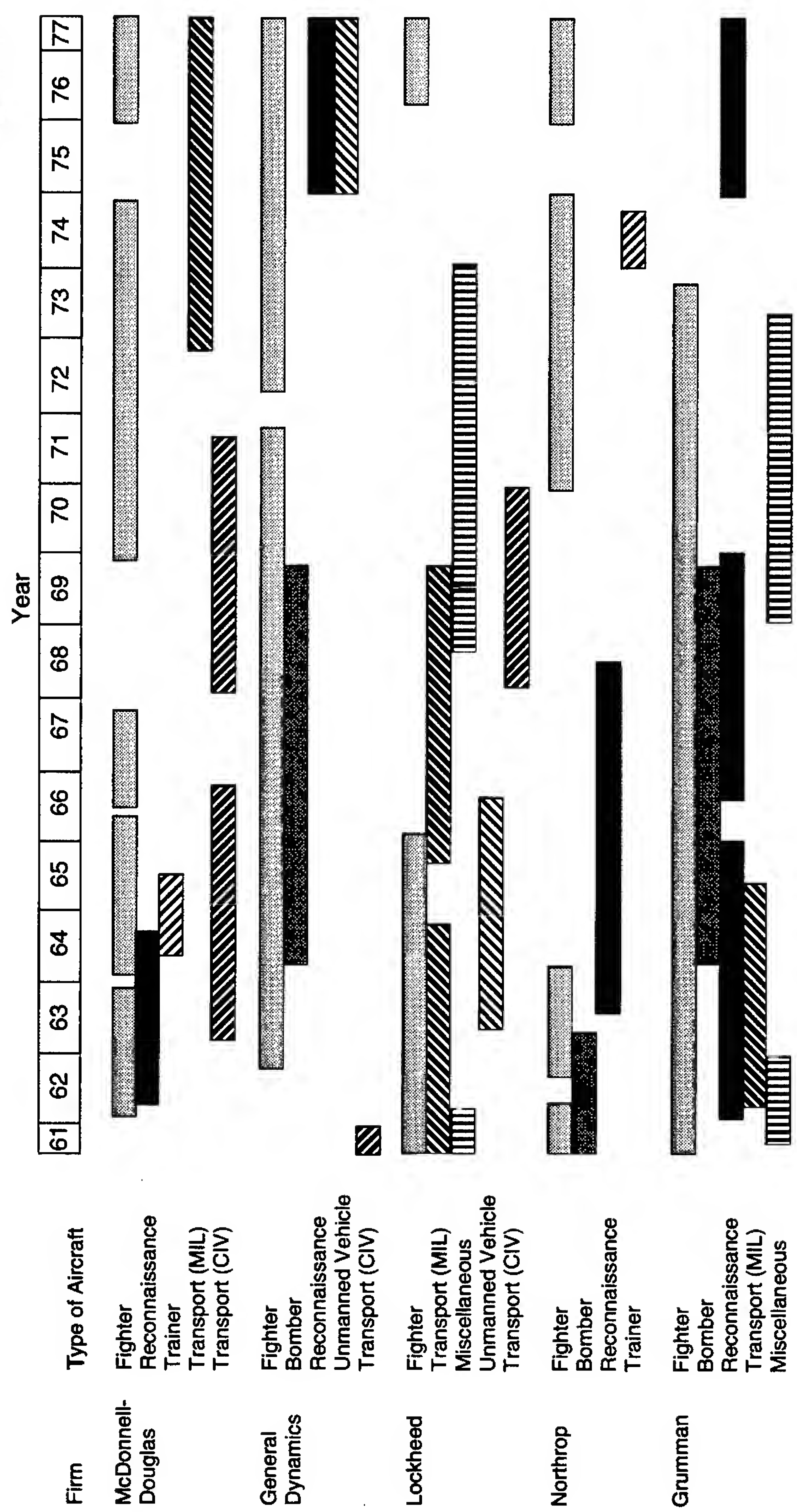
Experience and Specialization: The Continuity of Leadership

Nine prime contractors designed and flew a total of at least 40 distinct jet fighter designs during the 1940s and 1950s.[28] In 1961 at the beginning of the second period, five of these contractors remained widely recognized leaders in Air Force fighter R&D: General Dynamics/Convair, North American, Republic, Lockheed, and Northrop. Between 1945 and 1961, these five contractors developed and flew a total of 22 fighter and eight bomber designs. Convair, North American, and Republic constituted the first tier of fighter developers for the Air Force, with a total of 15 fighter designs and seven bomber designs among them that were developed and flown. Lockheed and Northrop made up a second tier of fighter developers for the Air Force, having flown seven fighter and one bomber designs during Period 1. The four leading Navy fighter developers—Grumman, McDonnell, Vought, and Douglas—designed and flew a total of 18 fighters during Period 1.

Between 1961 and 1977, the number of distinct new tactical fighter designs developed and flown declined significantly to under ten. As a result, four contractors in effect exited from the fighter R&D business because of their failure to win new contracts. These included two from the former first tier of Air Force developers—North American and Republic—and two Navy contractors—Douglas and Vought.

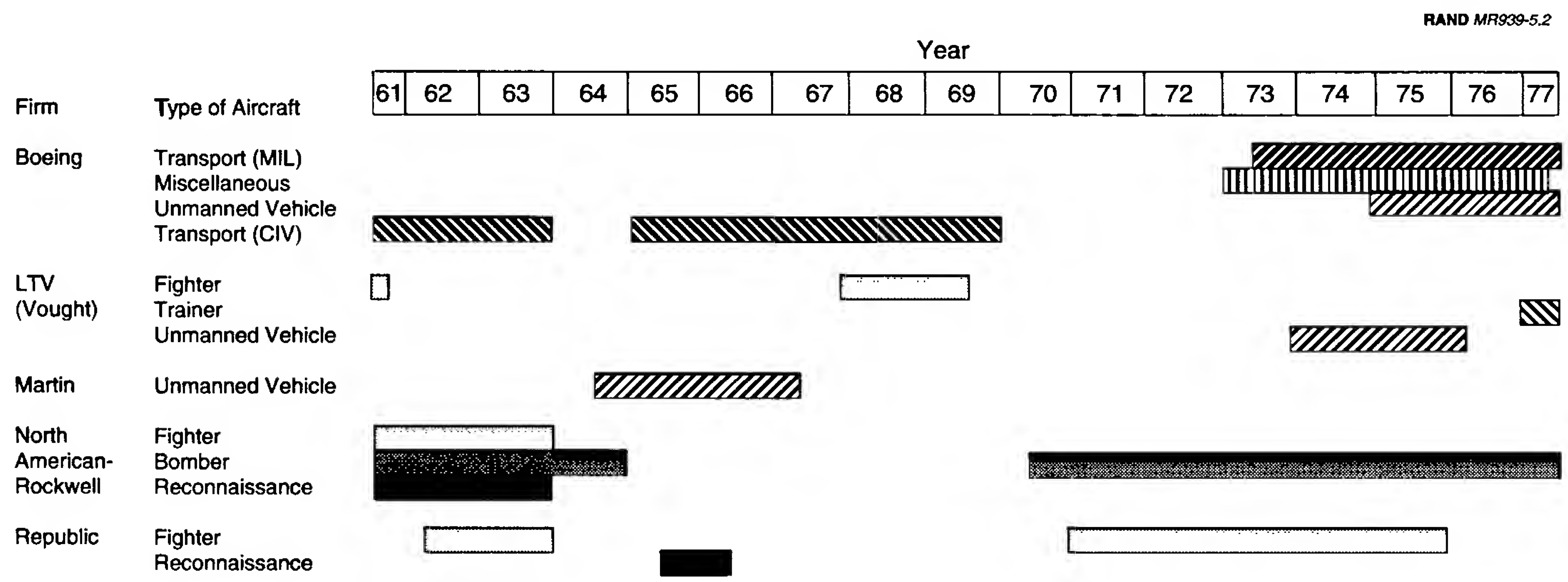
Yet the most active and successful fighter developers at the end of the second period remained the same companies that had held leadership positions at the end of the 1950s, as shown in Figures 5.1, 5.2, and 5.3. Thus, General Dynamics/Convair, arguably the leading developer along with North American, of Air Force combat aircraft at the end of the 1950s, retained a position of leadership by developing the F-111 and F-16. Grumman held on to the leadership position it had first acquired back in the 1930s by developing the F-14 and modifications of the A-6 Intruder naval attack aircraft. Northrop, long having specialized in the development of LWFs, teamed with McDonnell-Douglas for development of the F/A-18.

[28]If technology demonstrators and fighterlike X-planes are included, this number rises to 73.



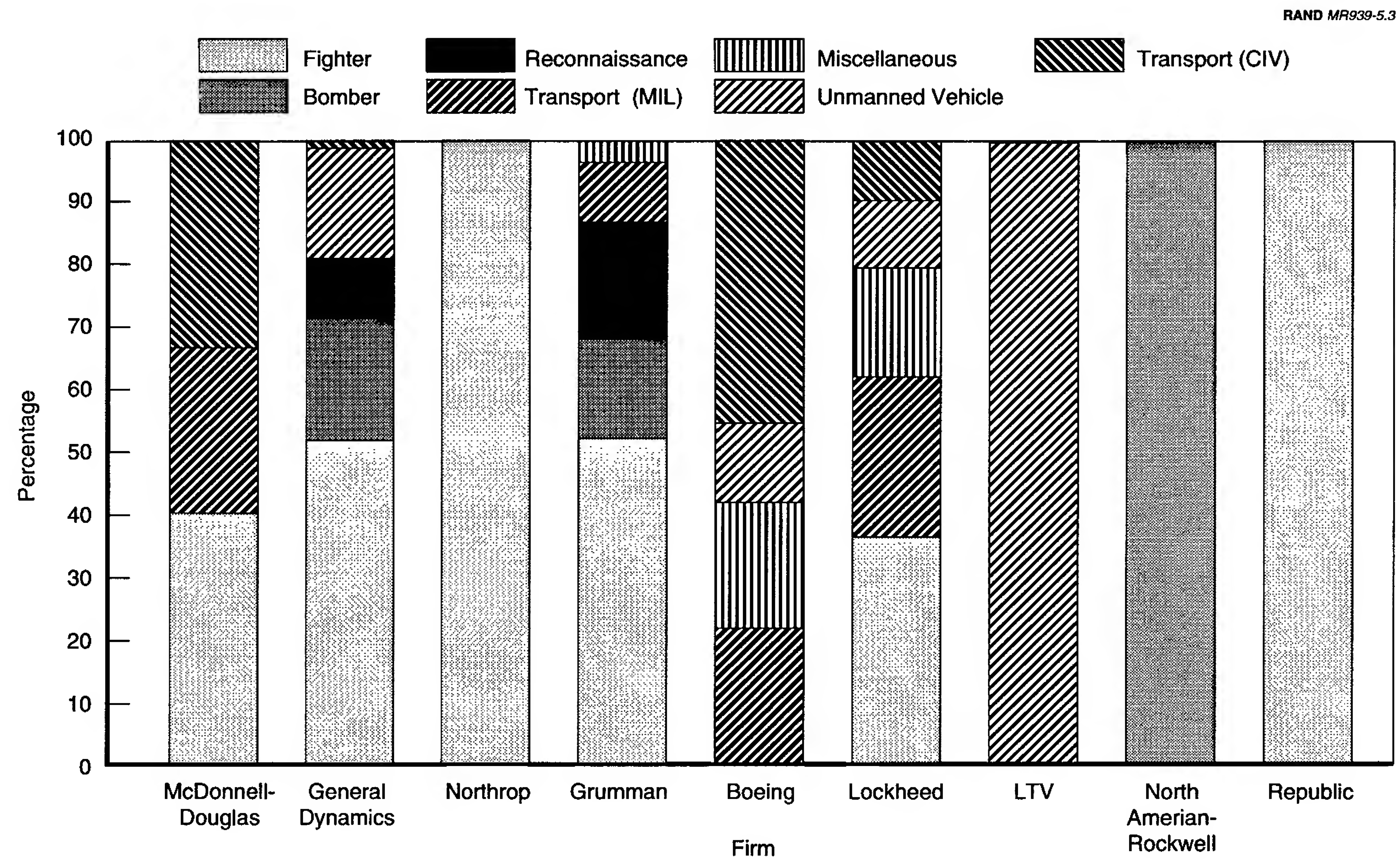
SOURCE: RAND database.

Figure 5.1—R&D Experience of Leading Fighter Developers in Period 2



SOURCE: RAND database.

Figure 5.2—R&D Experience of Other Prime Contractors in Period 2



SOURCE: RAND database.

Figure 5.3—Breakdown by Firm of Share of Experience by Types of Aircraft Relative to Firm's Total Experience in Period 2

McDonnell-Douglas, however, clearly stands out as the most successful fighter developer in the 1960s to mid-1970s, because of its development of modified versions of the F-4 for both the Air Force and the Navy; continued development of the A-4; development of the F-15, the Air Force's premier air-superiority fighter; and leading role on the F/A-18 and AV-8B programs for the Navy and Marines. This leadership role in both Air Force and Navy fighters is unique in postwar U.S. aerospace history but was perhaps predictable given McDonnell's successes in the 1950s with both Navy and Air Force programs. Perhaps most significant, of all the prime contractors—with the one exception of Republic—McDonnell had historically shown the strongest inclination to specialize and focus on fighter R&D. Even after the merger with Douglas, the focus of the facilities McDonnell-Douglas had accumulated in St. Louis from the 1940s through the 1970s remained unmatched and clearly seems to have contributed significantly to the success of this corporation.

But what of the other contractors that thrived in the 1940s and 1950s but stumbled in the following period? Most of them diversified into other aircraft types or niches, in response to the greatly reduced number of new fighter programs beginning with the McNamara era. North American, one of the most successful fighter developers from World War II through the 1950s, increasingly specialized in high-speed bombers, research aircraft, and space vehicles. This specialization grew directly from its pioneering R&D experience with very-high-speed aircraft beginning with the X-10 Navaho program and moving through the F-100, X-15, XB-70, XF-108, B-1A, and Space Shuttle. Lockheed focused on highly specialized fighterlike reconnaissance aircraft, such as the U-2 and SR-71, as well as large military and commercial aircraft. Republic and LTV remained alive with their attack aircraft programs and subcontracting, while Douglas concentrated on large military and commercial transports after merging with McDonnell.

As shown in Figures 5.1 and 5.3, the leading fighter developers during the 1960s to the mid-1970s continued to devote significant percentages of their overall corporate efforts to fighter R&D, as they had earlier. When measured in terms of the total work days between an initial hardware development start and a production start for any given project, 40 percent or more of the days of the four leading fighter developers spent on hardware R&D were spent on fighter development.

As in the first period, little correlation exists during the second period between success in commercial development and fighter or supersonic bomber R&D. Among the major prime contractors, only Lockheed, Douglas, and Boeing show any significant large commercial transport development work. None of these companies won a major fighter R&D contract during the 1960s to the mid-1970s. In contrast to the earlier period, the 1960s to the mid-1970s witnessed a

slight decline in specialization by service and in the practice of adopting evolutionary, incremental designs for new fighters. By itself or teamed with other firms, McDonnell-Douglas developed most of the new tactical fighters of the era for the Air Force, the Navy, and the Marines (F-4, F-15, F/A-18, AV-8B). General Dynamics departed dramatically from its earlier supersonic delta-wing design configurations with both the swing-wing F-111 and the lightweight F-16.

This situation resulted in part from the greatly reduced number of new program starts between 1961 and 1977 and from the Pentagon's efforts to consolidate R&D through more multirole, multiservice fighter programs. The TFX/F-111 and the F-4 programs, as shaped by the Pentagon under McNamara, consciously sought to reduce the number of new starts and to end specialized R&D programs for each service. Nonetheless, these trends did not significantly undermine the importance of specialization and incrementalism during the 1960s and 1970s compared to the 1940s and 1950s. In the first instance, McDonnell had already developed its unique multiservice track record in the earlier period by specializing almost exclusively in fighters, but selling them successfully to both the Air Force and the Navy. General Dynamics with the F-111 and F-16, Grumman with the F-14 and A-6, and Republic with the A-10 all continued their traditional service specializations throughout the 1960s and early 1970s. With the possible exception of the F-15, all of McDonnell's tactical fighter designs were clearly evolutionary and incremental. Grumman's F-14 and Northrop's YF-17 also drew heavily on earlier design concepts and R&D.

Thus, the characteristics of continuity of R&D leadership, specialization among contractors, and design incrementalism, which all were in strong evidence in the first period, remained reasonably well entrenched in the second period, once again apparently confirming the central importance of system-specific experience. No new firms entered the fighter development business, while four firms exited. This situation is to be expected given the fact that the later period was characterized by less revolutionary and dramatic rates of change in airframe and engine technologies than in the 1940s and 1950s, thus increasing the relative importance of system-specific experience, especially in a contracting market for new programs.

Competition and Prototyping

Despite the effective decline in the number of contractors active in fighter development programs and McNamara's emphasis on a systems-analysis approach to design competitions, the 1961–1977 period nonetheless witnessed widespread and intense competition and prototyping not unlike what characterized the earlier period. Indeed, at the design stage, the competition was even greater during the 1960s and 1970s than in the earlier period. Virtually

every major prime contractor submitted credible proposals in nearly every military aircraft effort during this period. With the relative decline of service specialization among contractors, the number of credible entrants in a competition often increased over what was typical earlier. Even a company that specialized in transports and subsonic bombers, such as Boeing, could become a very serious and credible contender in fighter competitions, at least at the design stage.[29] Most independent observers also considered North American Rockwell, Fairchild-Republic, and LTV to be very serious competitors throughout Period 2, even though they never won a fighter design competition.[30]

Despite the infamous "paper competitions" that McNamara's Whiz Kids advanced in the Pentagon, which contributed to the early problems experienced on the TFX and C-X (C-5A) R&D programs, Period 2 witnessed major new thrusts in competitive prototyping unmatched by anything seen since the late 1940s and early 1950s. The most obvious examples are the fly-offs between the General Dynamics YF-16 and Northrop YF-17, as well as the Northrop YA-9 and Republic YA-10.

Continuing Air Force and NASA Technology Leadership

Finally, the history of fighter R&D during the 1960s to the mid-1970s indicates that the U.S. Air Force and NASA continued to provide critical technology leadership, as they had done during the 1940s and 1950s. While research continued in the areas of very-high-speed flight during the 1960s with such test vehicles as the XB-70 and the X-15, this research was increasingly oriented toward technical problems posed by manned spacecraft, rather than fighters. However, government and industry engineers working together helped produce dramatic technology advances applicable to fighters in other areas. The single most important area was stealth technology, which is discussed in the next chapter.

Other significant areas included maneuverability, flight efficiency, and a wide variety of avionics, subsystems, sensors, and munitions technologies. Of particular importance for fighters in the 1970s and beyond were the development of both analog and digital FBW flight-control systems and the investigation of novel maneuvering regimes through the use of control configured vehicles

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[29]Various accounts claim Boeing was the initial winner in the TFX design competition. Some published sources reported that Boeing presented a proposal considered roughly comparable to those General Dynamics and Northrop provided on the LWF design competition for the Air Force. Boeing also reportedly did well on the F-X competition.

[30]Published accounts allege that Republic came in a close second on the F-X (F-15) design competition and submitted competitive proposals on the LWF program and other competitions. North American was a finalist on the F-X and is claimed to have been a serious contender on the F-14 program. Some accounts allege that LTV was a serious contender on the F-14, F-16, F/A-18, and F-5E programs.

(CCVs). These technologies made possible the highly maneuverable fighters of the 1970s and the stealth combat aircraft of the 1980s. A NASA program in the early 1970s used a modified Vought F-8C to develop digital FBW flight controls, later used on the McDonnell-Douglas/Northrop F/A-18 and newer versions of the F-16. The NASA/USAF CCV F-16 and the Advanced Fighter Technology Integration F-111 programs both contributed greatly to the optimal exploitation of the new flight-control technologies.[31]

These and many other technology-development programs helped American contractors reach the pinnacle of conventional jet-fighter design and development during the 1970s. Yet all of these developments were soon to be overtaken by a technology revolution of unprecedented operational significance for combat aircraft that was quietly under way in the "black" world of highly classified military R&D. The emergence of stealth technology, rendering combat aircraft nearly invisible to conventional radar, would dramatically alter the leadership roles of U.S. fighter contractors, as the American aerospace industry entered a new period of revolutionary technological change comparable in some respects to the dramatic changes witnessed during the 1940s and 1950s.

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[31]For a summary of many of the most important Air Force technology-demonstration programs since World War II, see Pace (1994).

Chapter Six

THE 1970s TO THE 1990s: THE STEALTH REVOLUTION

NEW TECHNOLOGY, NEW INDUSTRY LEADERS

The stealth era, which got fully under way in the mid-1970s behind a wall of strict secrecy, ushered in a new era of rapid technology change. Armed with precision-guided munitions, the new generation of American stealthy combat aircraft dramatically increased the potential combat effectiveness of air power. Developed and applied primarily by U.S. contractors, stealth technology catapulted American developers of military aircraft into an unquestioned position of world leadership. The stealth revolution transformed military aircraft airframe design and development and led to major changes in industry leadership in fighter R&D.

Stealth technology aims at reducing as much as possible the radar, IR, acoustic, and visual signatures of combat aircraft to avoid enemy detection, to enhance survivability and achieve surprise. The highest priority and most challenging aspect of stealth is achieving a low radar cross section (RCS). This is because radars can detect conventional aircraft at up to several hundred miles range, providing ample warning time for defenders, while IR, acoustic, and visual sensors have much shorter detection ranges in most situations.[1] Stealth became increasingly of interest to Air Force and DoD planners in the 1970s. The continuing development of a variety of technologies increased stealth's cost-effectiveness as a means of countering rapidly improving Soviet air-defense capabilities. In the case of the strategic bomber, stealth appeared to be the only way to ensure the survivability, and thus the continued existence, of penetrating manned bombers into the 1990s.

The key technologies for achieving low RCS manned combat aircraft included the development of advanced composite materials and fabrication processes for large load-bearing aircraft structures and engine structures; advanced radar-

[1]At very high and very low altitudes, IR suppression becomes increasingly important. See Bahret (1993), p. 1,377.

absorbing materials (RAMs) and application processes; devices and methodologies for accurately measuring RCS; significantly improved computers and advanced computer-assisted design processes to assist in shaping aircraft structure; and advanced FBW computer-controlled electronic flight-control systems to provide flight stability for aerodynamically unstable low-RCS designs.[2] Later, engineers also had to develop fire-control radars and other avionics with less-detectable emissions, such as low probability of intercept radar. Most of these technologies had been under development in the 1970s or earlier for a variety of applications, but Lockheed and Northrop first brought them all together in an operationally effective way for stealth combat aircraft.

The stealth era exhibits several broad characteristics in common with the first postwar period of great technological innovation in the 1940s and 1950s. Like the earlier period of fighter R&D, the stealth era witnessed a significant amount of technological change in the basic development of airframes and air vehicles that had the effect of leveling the playing field for several aerospace prime contractors. In terms of Hall and Johnson's categories, unique firm-specific experience and capabilities once again increased dramatically in relative importance compared to system-specific capabilities. Indeed, it can be argued that firm-specific experience became more important than system-specific experience during the stealth period.

Periods of major technological innovation and change can provide enhanced opportunities for new entries into specialized areas among the prime contractors. In the 1940s and 1950s, the turbojet engine revolution permitted such companies as McDonnell, which was founded in 1939 and had no major development contracts in World War II, to come out of nowhere and become a leading developer of both Navy and Air Force jet fighters. Leading fighter developers of the 1930s and 1940s, such as Bell and Curtiss, failed to accomplish the transition to jets successfully. Boeing, the dominant heavy-bomber developer of World War II, slipped behind North American and Convair in the mid-1950s in part because of its relative lack of experience in the rapidly advancing technologies associated with supersonic flight. Likewise, the stealth revolution permitted two companies—Northrop and Lockheed—which had specialized in niche combat aircraft areas and had not been the leading mainstream fighter and bomber developers in the 1960s and 1970s, to take a clear leadership role in stealth combat aircraft in the 1980s and 1990s. Conversely, the dominant mainstream fighter and bomber developers of the middle period—McDonnell-Douglas, General Dynamics, Grumman, and Rockwell—which had built their leadership based on their substantial expertise in conventional combat aircraft

[2]See Pace (1992), pp. 219–220.

RAND MR939-6.1

		1975	1980	1985	1990
Boeing	**(M)**	AGM-86 (ALCM)		**A-6F** **YF-22***	**F-22***
	(C)	757 767			777
GD	**(M)**	**F-16** **CCV F-16**	**AFTI F-16** **F-16XL**	**A-12*** **YF-22***	**NF-16D VISTA**
		BGM-109A/B, G (SLCM/GLSM)			**F-22***
Grumman	**(M)**	EF-111	X-29A		E-8 JSTARS
Lockheed	**(M)**	**XST**	**F-117** TR-1	**YF-22***	**F-22***
McDonnell	**(M)**	**F/A-18***	C-17	**A-12***	**F/A-18E/F**
		AV-8B		**F-15S/MTD**	
			T-45	**F-18 HARV** **YF-23***	
	(C)	MD-80		MD-11	MD-90
Northrop	**(M)**	**F/A-18***	**F-20**	**B-2** AGM-137 (TSSAM)	
			Tacit Blue	**YF-23***	
Republic	**(M)**		T-46		
Rockwell	**(M)**	HiMat	**B-1B**	X-31*	

*Collaborative program with other contractor(s).

SOURCE: RAND database.

(M) = military; (C) = commercial; bold = fighters, bombers, and related programs; underlined = missiles; normal = X-planes, commercial aircraft, and miscellaneous.

NOTE: Aircraft placement approximates beginning of full-scale development.

Figure 6.1—Selected Major Fixed-Wing and Cruise Missile Programs, 1975–1990

development, ended up losing most of the competitions for the new stealth combat platforms. Figure 6.1 shows many of the major bomber, fighter, missile, and space-vehicle programs of this period.

Lockheed appears to have arrived at its strong position as a leader in stealth partly because of good fortune related to firm-specific capabilities acquired from its niche specialties in the 1950s and 1960s. For its part, Northrop appears to have made a strategic corporate decision as far back as the 1960s to concentrate on stealth technologies as part of a strategy to break out of its second tier position among combat aircraft contractors by increasing its unique firm-specific capabilities.[3]

The F-104, the last fighter the Air Force procured from Lockheed before the stealth era, began development in the early 1950s. After this point, Lockheed continued to compete for numerous mainstream fighter and bomber programs but failed to win them. The company increasingly specialized in large aircraft (military and commercial transports and maritime patrol aircraft), as well as top secret, highly specialized reconnaissance aircraft developed at its famous "Skunk Works" facility in Burbank. However, a version of one of these aircraft—the Mach-3 SR-71 Blackbird—was briefly considered for procurement as a fighter-interceptor called the YF-12.[4]

Aircraft designed for covert strategic reconnaissance missions are, of course, intended not to be detected. Launching development of their U-2 reconnaissance aircraft in 1954, Lockheed designers sought to ensure survivability and avoid detection by making the aircraft small and providing it with very-high-altitude capabilities. Some studies were conducted on reducing the U-2's RCS, but they did not meet with great success. The follow-on to the U-2, however, was the first aircraft designed from its inception to reduce RCS. Eventually known as the SR-71 Blackbird, this remarkable aircraft was approximately the same size as the Convair B-58 and flew Mach 3+ at altitudes over 80,000 feet but had the RCS of a small private aircraft.[5] Selected as the developer of this U-2 follow-on in 1959, Lockheed configured the aircraft from the beginning with low RCS in mind. By the mid-1960s, a full-scale model of the SR-71 was being tested on an RCS test range. Lockheed employed RAMs for structural edges and

[3]Most of the details about the history of stealth R&D are still sketchy or remain classified. The account presented here has been pieced together from a variety of open sources that may not be accurate and often tend to be sketchy. A full and accurate account of this period will have to await the declassification of substantially more information.

[4]Briefly considered as a F-108 replacement, several Blackbirds were modified into a fighter-interceptor configuration called the YF-12.

[5]Rich and Janos (1994), pp. 23–24.

radar-absorbing coatings for the fuselage to achieve the first stealthy military aircraft.[6]

In developing the stealthy SR-71, Lockheed apparently drew heavily on earlier government-supported research efforts. Although not widely known until recently, the U.S. Air Force Avionics Laboratory at Wright-Patterson Air Force Base, working closely with industry, supported much of the pioneering theoretical and applied research on reducing radar signature in the 1950s. Efforts to measure aircraft RCS accurately began early in that decade. As engineers developed better methods for measuring RCS, interest in reducing RCS increased. Engineers examined the echo characteristics of specific aircraft on a special measurement range built for the purpose. By the mid-1950s, engineers began to investigate what elements of an aircraft shape and configuration contributed most to radar echo and how the configuration could be changed to reduce radar echo. In 1955, a major effort was launched to develop RAM to apply to aircraft structures. By the end of the decade, a Lockheed T-33 had been coated entirely in RAM and tested extensively. Screens for air inlets and masking of exhaust pipes were developed on two B-47 test-bed aircraft. Early on, this research had demonstrated that aircraft shape and configuration were the most important contributors to radar echo and that significant reduction in RCS required full application of RCS concepts to the basic aircraft design from the beginning of development. These results clearly influenced Lockheed's design approach to the SR-71.[7]

Lockheed's experience with developing low RCS configurations and materials grew in the 1960s as the Skunk Works continued its specialization in covert reconnaissance aircraft. Basic research on materials, aerodynamics, and other areas continued at Lockheed's Rye Canyon laboratories. Early in the decade, Lockheed began development of a stealthy reconnaissance drone, which was originally intended for launch from the SR-71. Called the D-21, the drone entered a flight-test program in 1966. Shaped like an SR-71 nacelle with blended wings attached, the small unmanned stealth vehicle reportedly had very good performance: Weighing only 13,000 lbs. loaded, it reportedly had an

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[6]Lockheed and Convair competed for this top-secret CIA project. Convair submitted designs for small aircraft launched from the B-58 that would utilize ceramics for low RCS and heat resistance. In addition to fuselage shaping, Lockheed's design incorporated radar-absorbing plastic materials on the leading edge flaps and control surfaces, as well as ferrous coatings and other composite materials on the fuselage. While North American did not know it at the time, the go-ahead for the Lockheed Blackbird contributed directly to the cancellation of North American's Mach-3 F-108 Rapier, as well as to rejection of proposals to save the XB-70 program by modifying the bomber into a strategic reconnaissance aircraft. See Rich and Janos (1994), p. 24; Lynch (1992), p. 23; and Sweetman and Goodall (1990), pp. 13–14.

[7]A fascinating account of early Air Force research on stealth can be found in Bahret (1993).

intercontinental range and could attain speeds of nearly Mach 4 and altitudes of 100,000 feet.[8]

Other companies worked on various aspects of stealth in the 1960s. Ryan Aeronautical Company produced a wide variety of stealthy reconnaissance drones beginning in 1960 that included fuselage shaping and RAM.[9] General Dynamics, the loser in the U-2 competition, built an extensive RCS range and tested its TFX designs there. The firm later built another major range for the Air Force. Apparently, Northrop Corporation began concentrating on stealth research in the mid-1960s and gained important experience on stealth during this period, although few details are publicly available. According to one account, Northrop's research focused on attaining very low RCS without compromising aerodynamic performance capabilities. By the early 1970s, the Defense Advanced Research Projects Agency (DARPA) was funding much of this research under a highly classified program called Harvey.[10]

Maintaining good aerodynamic capabilities and maneuverability had always been viewed as a problem in shaping airframes for stealth, and may explain why so many years passed before contractors made serious attempts to develop very low RCS fighters and bombers. At one point, Lockheed officials considered offering a modification of the D-21 to the Air Force as a stealthy attack aircraft. But, as discussed in Chapters Four and Five, fighter design in the 1960s was moving away from an emphasis on high speed and altitude capabilities to enhanced maneuverability and agility. Engineers in the 1960s believed that the fuselage shaping and added weight of RAM treatments to obtain low RCS would unacceptably degrade required aerodynamic qualities. To attain very low RCS, the aircraft might not even be controllable given the flight-control technology of the 1960s. By the early 1970s, however, many of these problems appeared more amenable to solution. General Dynamics had developed a sophisticated analog FBW flight-control system for the YF-16. Progress was being made in RAM materials and in the development of lightweight carbon-fiber composite materials for structural use.

DEVELOPMENT OF THE F-117 NIGHTHAWK

As a follow-up to Harvey and other research programs, DARPA sent out RFPs for competitive study contracts to Northrop, McDonnell-Douglas, General Dynamics, Fairchild, and Grumman in 1974 to develop design concepts for a

[8]Rich and Janos (1994), pp. 22–23; Sweetman and Goodall (1990), p. 15.

[9]See Wagner (1982).

[10]See Dorr (1995), p. 11, and Sweetman (1992), p. 18.

very low RCS combat aircraft.[11] Only the first three firms responded. Lockheed also soon joined the competition.[12] Its engineers developed a highly unconventional faceted design nicknamed the "Hopeless Diamond," which contained only two-dimensional flat surfaces. This was because RCS could only be calculated with high precision for two-dimensional surfaces given the state of knowledge and the capability of computers at the time. Northrop proposed a more conventional delta-wing stealth design with the air inlet on top, which used a combination of angular and rounded surfaces.[13] McDonnell proposed a variant of its "Quiet Attack" aircraft design that had been developed earlier under a contract for the Office of Naval Research. DARPA soon realized that both Lockheed and Northrop had proposed design concepts that were revolutionary in their potential to reduce RCS. In October, DARPA awarded these two companies follow-on contracts to develop their design concepts further. The two companies built models of their designs, which engineers then tested in early 1976 on a fixed pole in a competitive "fly-off" at the Air Force's radar range in New Mexico. In April, DARPA informed Lockheed that it had won the competition.

Under a program code-named Have Blue, jointly sponsored by the Air Force and DARPA, Lockheed received a new contract to build and flight test two small, manned technology demonstrators labeled the Experimental Survivable Testbed (XST)[14] to demonstrate and validate its stealth technologies and design. Except for their shape and materials, these test vehicles were largely conventional, using mostly off-the-shelf components and subsystems, such as a modified version of the General Dynamics F-16 FBW flight-control system complete with its side stick controller, and the landing gear from the Northrop F-5.

Shipped in a C-5A transport from the Burbank Skunk Works to a remote test facility, the Lockheed XST test aircraft first flew in December 1977. The first technology demonstrator was destroyed in May 1978 because of a problem with the landing gear. The first flight of the second test vehicle took place in July; flight testing continued for a year. In July 1979, the second XST technology

[11]The most detailed book-length account of the development of the F-117 can be found in Aronstein and Piccirillo (1997).

[12]Pentagon officials had not sent out the original RFP to Lockheed because they were unaware of the firm's pioneering stealth work on the highly classified SR-71 and D-21 programs for the CIA. Each of the original five contractors received $1 million, but Lockheed had to finance its effort with corporate funds. See Rich and Janos (1994), pp. 22–25.

[13]Sweetman (1992), p 23.

[14]Although open press sources usually claim that XST stands for "Experimental Stealth Technology Testbed," Dorr insists that "Experimental Survivable Testbed" is actually correct. See Dorr (1995), p. 11.

Photo 6.1—Developed in great secrecy in the late 1970s and early 1980s, the Lockheed F-117 Nighthawk became America's first operational stealth fighter and saw combat in Panama and during Desert Storm in Iraq.

demonstrator crashed after an onboard fire. Although this second crash ended the XST flight-test program, the Air Force remained extremely pleased with the results of this pioneering effort. Have Blue had successfully demonstrated the feasibility of developing very low RCS combat aircraft.[15]

The Air Force moved ahead rapidly to support development of an operational stealth fighter-attack aircraft based on the XST. In November 1978, Lockheed received a full-scale development contract for a subsonic, low RCS fighter-attack aircraft later designated the F-117. The program, code-named Senior Trend, called for procurement of five developmental prototypes and 15 production aircraft. Drawing on the lessons learned from the XST flight-test program, engineers significantly changed and enlarged the basic XST design. For example, the tail fins of the F-117 canted outward instead of inward. The first flight took place in June 1981. Flight testing with up to four prototype aircraft continued through 1982.

The F-117 went on to complete development and become an effective fighter-attack aircraft tested in combat. The Air Force established the elite 4450th Tactical Group in 1979 to fly the F-117 once development was complete. In October 1983, the 4450th achieved initial operational capability with the new aircraft.[16] Seven years later, during Desert Storm in Iraq, the F-117 demonstrated the operational benefits of stealth when combined with precision-guided munitions and other assets.

EMERGENCE OF THE ADVANCED TECHNOLOGY BOMBER PROGRAM

Northrop's loss to Lockheed for the XST did not end its pioneering efforts in stealth. In 1976, the Air Force and a variety of government agencies were supporting several contractor studies to examine operational applications of stealth technology to different mission areas and types of air vehicles. A government "Blue Team" was also looking at similar issues. These studies led to recommendations to the Air Force encouraging the development of low-RCS fighter, attack, and bomber aircraft, as well as cruise missiles and unmanned aerial vehicles. In response, the Air Force is said to have initiated the Covert Survivable In-weather Reconnaissance/Strike (CSIRS) program, which led to a decision to develop a stealthy tactical attack fighter and a tactical reconnaissance platform. Lockheed then went on to develop the F-117 stealth attack fighter based on its XST technology demonstrators, which would later become America's first very-low-RCS operational combat aircraft.

[15]The most extensive account of Have Blue and F-117 development can be found in Rich and Janos (1994). Also see Dorr (1995).

[16]See Kennedy et al. (1992).

According to unconfirmed press accounts, the Air Force did indeed move ahead in the late 1970s and early 1980s with studies for a stealthy Tactical High-Altitude Penetrator (THAP) reconnaissance platform. Northrop's THAP design allegedly was the leading submission in the CSIRS program. Some accounts claim that the Air Force began RCS and wind-tunnel tests of the Northrop proposal in 1976.[17]

The government has never confirmed the existence of the THAP program. However, according to recently released information, the Air Force and DARPA did award Northrop a sole-source contract in 1978 for development of a new stealthy technology demonstrator called Tacit Blue.[18] Initially, Tacit Blue was part of the Pave Mover program aimed at developing a stealthy reconnaissance aircraft with a low probability of intercept radar, for operation very close to the forward battle lines. Reportedly, the Air Force soon concluded that the battlefield ground-surveillance mission could be conducted by a larger, more conventional aircraft flying much farther behind the front lines. This led to the Grumman E-8 Joint Surveillance Target Attack Radar System surveillance aircraft, which was based on the Boeing 707 airliner airframe. The Air Force decided to continue flight testing the Tacit Blue demonstrator as a generic test bed for stealth technologies.

The Tacit Blue flight-test program lasted from its first flight in February 1982 to early 1985. The single-seat, relatively low-speed test aircraft was about the size and weight of a lightweight fighter. According to one senior Air Force officer, Tacit Blue represented the first attempt at using "curved linear or Gaussian surfaces to achieve signature reduction," instead of the two-dimensional "Hopeless Diamond" approach employed on the F-117.[19] It is unclear what relation there is between Tacit Blue and the alleged THAP program. They may indeed be one and the same. However, revelation of the Tacit Blue program does, in the words of one journalist, "fuel speculation as to whether it was succeeded by another manned low-observable reconnaissance platform."[20]

What is far more certain is that, in 1978, Lockheed received a two-year concept-formulation contract to study the development of a stealthy medium tactical bomber in the F-111 class, which could be based on a scaled-up version of the F-117. Over time, the Lockheed design evolved toward a flying wing concept, because such an approach provided low RCS and good wing efficiency for long

[17]Discussions of the THAP and TR-3A programs appear highly speculative and have never been verified. See Scott (1991b), p. 20; Scott (1991c), p. 20; and Baker (1994a), pp. 143–144.

[18]This account is drawn from Lopez (1996), p. 17. Because of the lack of precise development dates, Tacit Blue is not included in the database.

[19]LtGen George Muellner, quoted in Lopez (1996), p. 17.

[20]Lopez (1996), p. 17.

range and a large payload. Later, Northrop also began proposing bomber designs and received its own design study contracts. Northrop obviously gained enormous experience on designing low-observable aircraft with rounded shapes through the Tacit Blue program. Northrop may also have drawn on the experience from other technology demonstrators that were allegedly under development at the time. Eventually, Northrop developed its N-14 design, a flying wing that had many design approaches in common with the claimed THAP/TR-3A designs.[21]

The Advanced Technology Bomber (ATB) program soon evolved into a very high-stakes competition between the two emerging leaders in stealth technology: Lockheed and Northrop. In early 1981, at DoD urging, the two contractors sought out team partners in order to provide more resources to support such a potentially large program. Lockheed teamed with Rockwell, and Northrop teamed with Boeing and LTV. These were ideal teams from the perspective of experience. Lockheed, of course, was the pioneer developer of the first stealth fighter, and Rockwell, with its XB-70, B-1A, and B-1B, was the leading bomber developer of the last two decades. Northrop also benefited from Boeing's long experience with bombers and its vast knowledge of large-aircraft development. Its lack of experience in supersonic fighter and bomber development was irrelevant, since the stealth bomber would be subsonic. In addition, both Boeing and LTV were industry leaders in composite materials design and manufacture, particularly in the area of large load-bearing structures.

As in the case of the XST several years earlier, the Air Force organized a "shoot-out" between the two competing designs in May 1981 at a radar range to determine which had the lower RCS. The Air Force also conducted wind-tunnel tests to calculate lift-to-drag ratios to determine potential range. In October, the Air Force formally awarded the ATB development contract to Northrop. Ben Rich of Lockheed claims that his company's design tested with a lower RCS. However, the Lockheed proposal called for a considerably smaller aircraft than the Northrop submission, with inferior range and payload capabilities.[22]

Northrop's greater experience in directly related design and technology areas may have been the key to its victory in the competition. As one published account notes, developing the ATB entailed significant technological risks relating to the aircraft's "complex curvatures, exotic materials, and other stealth methods."[23] In 1981, Northrop was developing Tacit Blue and may have already been flying a prototype THAP-like reconnaissance vehicle for many months at

[21]Rich and Janos (1994), pp. 302–307; Baker (1994a), p. 144.

[22]Rich and Janos (1994), pp. 309–311.

[23]Bill Scott (1991a), pp. 7–8.

the time it won the ATB competition. Northrop would have accumulated more experience than Lockheed in designing and developing the large unfaceted stealth designs necessary for long-range heavy bombers with Have Blue and other programs that might have existed.[24]

THE F-22: DEVELOPING THE FIRST STEALTHY AIR-SUPERIORITY FIGHTER

The greatest and most-sought-after prize of the stealth era, however, remained the development contract for the first Air Force supersonic stealth fighter to replace the F-15 air-superiority fighter. As effective as it was, the F-117 remained a subsonic attack aircraft used primarily for air-to-ground operations. The leading prime contractors soon realized how important the competition for the next Air Force air-superiority fighter would be. In all likelihood, it would be the only opportunity to develop a new first-line fighter for the next decade or more. Because of anticipated R&D costs and multiple competing demands on the defense budget, the Pentagon envisioned at most only one major new fighter development program and one major attack aircraft effort for the 1980s and 1990s: the Advanced Tactical Fighter (ATF) and the Advanced Tactical Aircraft (ATA). At least eight remaining U.S. prime contractors competed strenuously for these two development efforts: General Dynamics, McDonnell-Douglas, Lockheed, Northrop, Boeing, Grumman, Rockwell/North American, and LTV. Very likely some of the losers would ultimately have to withdraw as a prime contractors from the fighter-attack aircraft market.

The U.S. Air Force launched the ATF program in June 1981 with a Request for Information to U.S. prime contractors. At this time, the U.S. Navy was examining the possibility of seeking a new common fighter (labeled the VMFX) to replace both the Grumman F-14 fighter and the Grumman A-6 attack aircraft.[25] In 1983, however, the Navy dropped this approach as too expensive and replaced it with a new plan to upgrade existing F-14s and A-6s and to procure a new stealthy attack aircraft, the ATA. Thus, after 1983, U.S. contractors could expect at most only one major development program for a new air-superiority fighter and one other program for an attack aircraft over at least the next decade.

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[24]Available sources claim that Northrop's flying wings from the late 1940s—the XB-35 and YB-49—provided little data and few insights relevant to the ATB development effort. This was because most engineers involved with the earlier efforts had long since retired, and Northrop had great difficulty locating test data that had been recorded during the earlier programs. However, engineers and test pilots did consult extensively with pilots who had flown the YB-49. See Scott, (1991), pp. 9, 60.

[25]Boeing won a contract for a major upgrade program for the A-6. The radically changed A-6F includes a new all-composite wing designed and developed by Boeing. Some observers have claimed that Boeing specifically sought this program to add to its experience base for future fighter R&D competitions.

As was the case during the early stages of the F-X/F-15 program nearly two decades earlier, considerable debate existed initially within the Air Force and Pentagon regarding the most desirable performance characteristics for the ATF. Once again, experts debated even more basic questions, such as multirole versus dedicated air superiority and interservice commonality. During 1982, a consensus began to emerge that a modified version of the F-15 or F-16 could perform the air-to-ground role, permitting the ATF to be optimized for air superiority.[26] By mid-1983, the ATF had clearly been defined as an F-15 replacement. The Air Force decided to seek supercruise capability (the ability to cruise at supersonic speed without afterburner) and engines with vectoring nozzles for short takeoff and landing (STOL) capability, combined with stealth and F-15/F-16–class maneuverability. The Air Force further refined the ATF requirement in 1984 and funded technology-development programs applicable to the ATF, such as efforts to develop antenna arrays for active phased-array fire-control radars and the F-15 STOL and Maneuver Technology Demonstrator program (S/MTD, the NF-15-B).

In September 1985, the Air Force sent out RFPs for a demonstration and validation (dem/val) phase for the ATF. Seven prime contractors responded with serious design proposals. The Pentagon and the U.S. Air Force selected Lockheed and Northrop in October 1986 to lead competing teams during a planned 54-month dem/val phase of the ATF development program. Only one team, of course, would receive the final award for full-scale development at the end of the competitive dem/val stage. In 1986, the Navy also awarded competitive design contracts for the ATA to two teams: one led by Northrop that included Grumman and LTV, and one with McDonnell-Douglas and General Dynamics as equal partners.

These two team leaders, of course, were the leaders in stealth aircraft R&D. According to at least one open source, McDonnell-Douglas and General Dynamics had been considered the leading contenders in the very early phases of the program because of their experience in conventional fighter development. But Lockheed and Northrop, it is claimed, eventually submitted ATF design proposals that were considered clearly superior to those of the other contractors in the area of stealth, because of these two firms' far more extensive knowledge and experience with stealth technologies.[27] According to another

[26]General Dynamics and McDonnell-Douglas developed prototypes of their competing modification proposals, called the F-16XL and F-15 Strike Eagle, respectively, which first flew in 1982. Two years later, the Air Force selected McDonnell-Douglas's entry for full-scale development as the F-15E. The F-16XL and F-15E programs had an effect on the ATF program parallel to the decision to procure the LTV A-7 in the 1960s, as discussed in Chapter Four, a decision that permitted the F-X requirement to focus on the mission of air superiority.

[27]Sweetman (1991a), p. 36.

published account, the Air Force rejected the McDonnell-Douglas design as insufficiently stealthy and too conservative, while Boeing was rejected in part because of its lack of recent fighter developmental experience.[28]

To share the financial risk and the experience base for the only new first-line fighter program expected for decades, the Air Force encouraged the competing prime contractors to team up in groups. In the case of the ATF, the two groups chosen as finalists were in many respects "dream teams." The Lockheed team combined the Skunk Works' unquestioned leadership in stealth technology, built up with the XST and F-117 efforts, with General Dynamics' skills in fighter development, based on the F-16 and F-111, and Boeing's extensive experience in composite materials and structures from commercial programs, the A-6F and the B-2 efforts. The second ATF team drew on Northrop's experience in stealth technology, dating back to the XST and B-2 programs, as well as its skills in fighter development, based on the YF-17/F-18 and the F-5 series.[29] Northrop teamed with McDonnell-Douglas, the leading U.S. fighter developer of the 1960s and 1970s.

In the case of the ATA, Northrop again provided stealth and fighter R&D expertise, while its team members, Grumman and LTV, shared their long experience with developing naval fighter and attack aircraft. On the other hand, while the McDonnell-Douglas/General Dynamics team appeared unmatched in conventional fighter-development experience, it seemed relatively less strong in stealth aircraft R&D, particularly in General Dynamics' case. More is said on this point later.

In April 1991, after more than four years of development work and an extensive flight-test program, the Air Force selected the Lockheed/General Dynamics/ Boeing YF-22 for full-scale development as the next Air Force air-superiority fighter. Reportedly, the Air Force considered both prototypes to be outstanding, but believed the YF-22 was a more balanced design and preferred the Lockheed industrial team.[30]

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[28]Sweetman (1991b), p. 34. However, as in the case of past Boeing design proposals dating back to the TFX/F-111, its ATF design proposal reportedly fared quite well on its own merits, allegedly coming in fourth in the competition. Sweetman (1991a), p. 37.

[29]In the 1970s, Northrop developed a much-improved export fighter derived from the F-5E. Originally called the F-5G, this fighter was later designated the F-20 Tigershark. Although highly capable, the F-20 was never purchased by a foreign government, in part because the U.S. government began supporting foreign sales of first-line USAF fighters, such as the F-16. Northrop eventually terminated the F-20 program.

[30]Sweetman (1991b), p. 40. Allegedly, the YF-23 was faster and stealthier, but the YF-22 was more maneuverable.

Photo 6.2—America's first-generation stealth combat aircraft, the Northrop B-2 bomber and Lockheed F-117 attack fighters, accompanied by a Lockheed (formerly General Dynamics) F-16 in the foreground.

Photo 6.3—The Lockheed/Boeing/General Dynamics YF-22 and the Northrop/McDonnell-Douglas YF-23 being refueled in flight by a Boeing KC-135 Stratotanker.

THE ROLE OF EXPERIENCE IN THE STEALTH ERA

The critical importance of experience in advanced composites and other stealth technologies in the development of large stealthy flying wing designs may be illustrated by the problems encountered on the ATA, or A-12, program. As noted above, the ATA program was launched in the early 1980s to provide a stealthy carrier-based attack aircraft to replace the aging Grumman A-6 Intruder. Later, officials decided that a modified version of the ATA would also replace the Air Force F-111 in the tactical bomber role. In November 1984, two contractor teams won preliminary concept-development contracts for the ATA: McDonnell-Douglas/General Dynamics and Northrop/Grumman/LTV. Both teams won follow-on contracts in June 1986 to refine their design proposals in anticipation of selection of one of the teams to lead full-scale development. Northrop's team proposal envisioned a larger and heavier aircraft than its competitor, with a projected development cost $1.1 billion dollars more than for the design the McDonnell-Douglas/General Dynamics team submitted.[31] In January 1988, the Navy selected the McDonnell-Douglas/General Dynamics team primarily on cost grounds. Unfortunately, by mid-1990 the A-12 program was at least $1 billion over cost and 18 months behind schedule. In January of the next year, Secretary of Defense Cheney canceled the program.

The cancellation of this program caused great controversy and acrimony between the contractors and the government. But clearly, the R&D program had run into serious problems when cancellation occurred, and many of these problems appear to have been caused by the contractors' relative lack of experience in critical composite technologies related to stealth. In the words of the "Beach Report," the official administrative inquiry into the A-12 cancellation,

> The primary problem encountered during FSD was weight growth due to the thickness of the composite material necessary for the structural strength required to support the stress and loads experienced by carrier-based aircraft. *Both contractors have limited experience in building large composite structures* and, in large measure, have had to develop the technology as the program progressed.[32]

Apparently this was an especially difficult problem for General Dynamics, which had never developed an aircraft that incorporated large load-bearing structural components made out of composites. According to one DoD expert, General Dynamics encountered such severe problems in manufacturing large load-bearing composite structures that it sought to off-load as much of the

[31]U.S. House of Representatives (1992a), p. 186.

[32]U.S. House of Representatives (1992b), p. 244. Emphasis added.

work as possible onto McDonnell-Douglas.[33] Indeed, the contractors later sued the government for allegedly failing to transfer composite and stealth technologies to them that were necessary to develop the aircraft and that, by implication, these companies apparently did not possess during development of the A-12. According to one press account, the contractors claimed that the government failed to provide technical data on stealth technology from the F-117, B-2, and other stealth projects,

> such as the types of composite materials necessary to cloak aircraft from enemy radar.... Lacking that information, McDonnell and General Dynamics say, their engineers flailed away for many months. Using heavier materials, they ultimately increased the plane's weight by almost one-third. The cost zoomed skyward.[34]

The early Navy assessment of the original contractor proposals also seems to bear out a lack of experience at the contractor level in critical stealth technologies. The Navy study concluded that the cost projections in the McDonnell-Douglas/General Dynamics proposal were at least $500 million too low. Assuming the contractors did not purposely underbid, this very low bid could reflect a lack of understanding of the complexity and difficulties involved in developing and manufacturing an airframe composed almost entirely of composite materials. Investigators also determined that the original McDonnell-Douglas/General Dynamics weight estimates were unrealistically optimistic. Nonetheless, the Navy selected the McDonnell-Douglas team anyway because, even after adjusting for optimistic cost estimates, the Northrop proposal was still much more expensive, in part because Northrop had proposed a larger aircraft.[35]

Interestingly, the Navy assessment of the Northrop proposal resulted in virtually the same cost numbers and weight estimates as the contractor provided. This could indicate a greater realism on Northrop's part due to experience. Northrop had already developed Tacit Blue and may have recently completed development of a THAP-like triangular delta flying-wing design—if indeed such a program actually existed—which may have been very similar in concept to the A-12, and was of course deeply involved in the B-2 R&D effort. Combined with Grumman's experience with the A-6 and many other naval aircraft, and LTV's expertise in composite structures and naval aircraft, the Northrop team's experience may have contributed to more realistic estimates of cost and technological risk.

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[33]U.S. House of Representatives (1992a), p. 204.

[34]Mintz (1992).

[35]U.S. House of Representatives (1992a), p. 186.

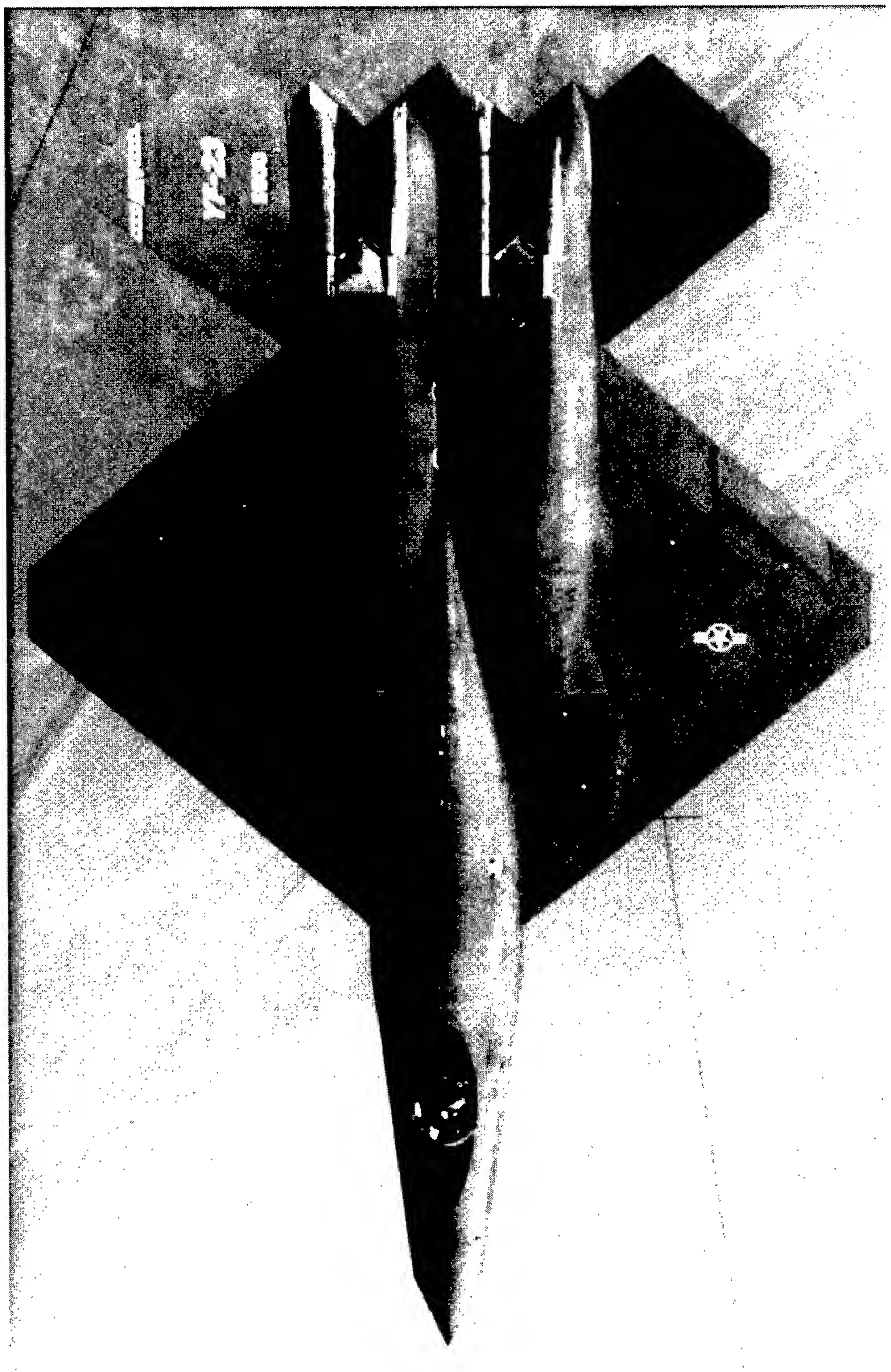


Photo 6.4—The Northrop/McDonnell-Douglas YF-23 flew in a three-month comparative test program with the YF-22 in early 1991. That April, the U.S. Air Force selected the YF-22 for full-scale development.

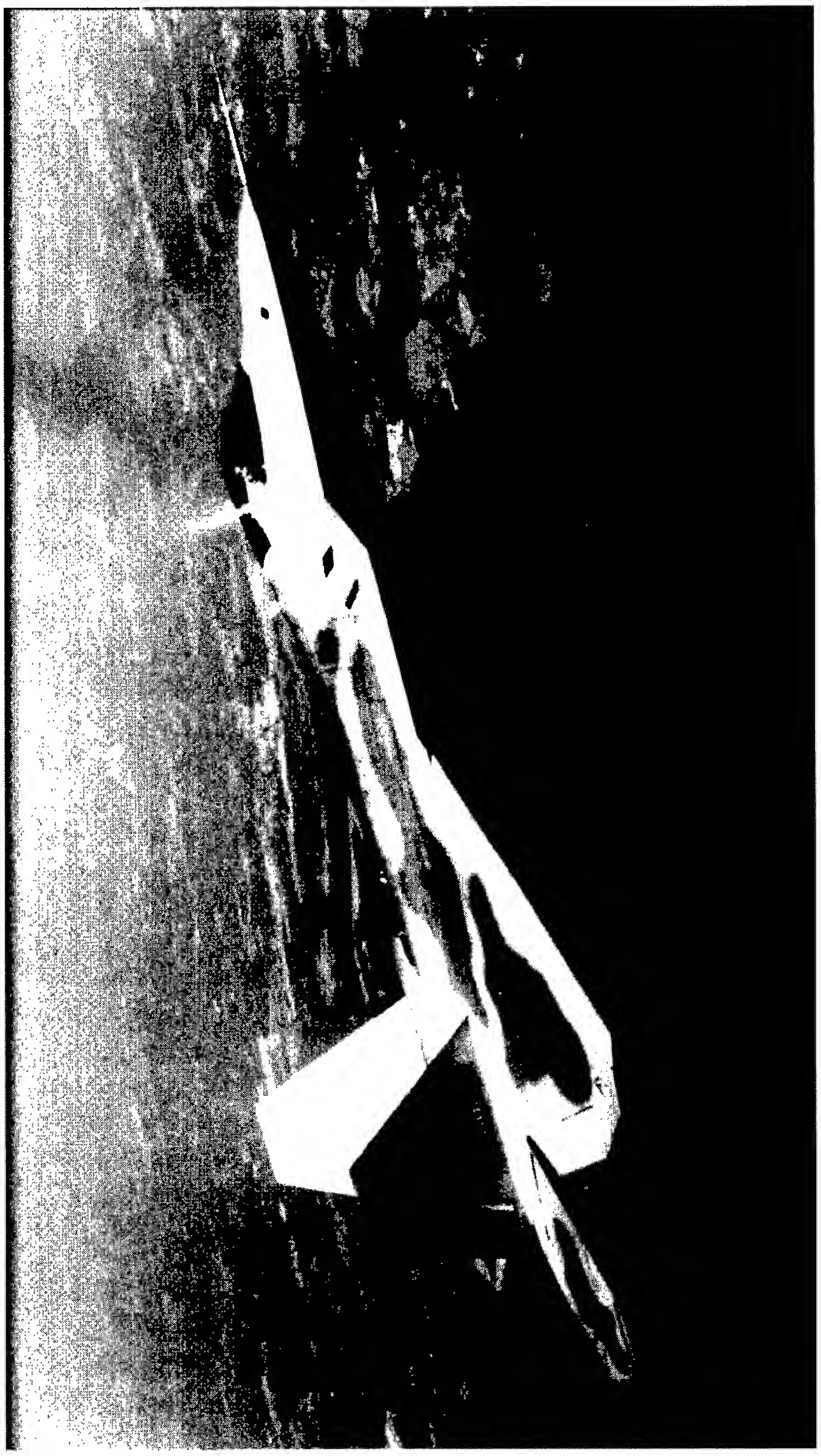


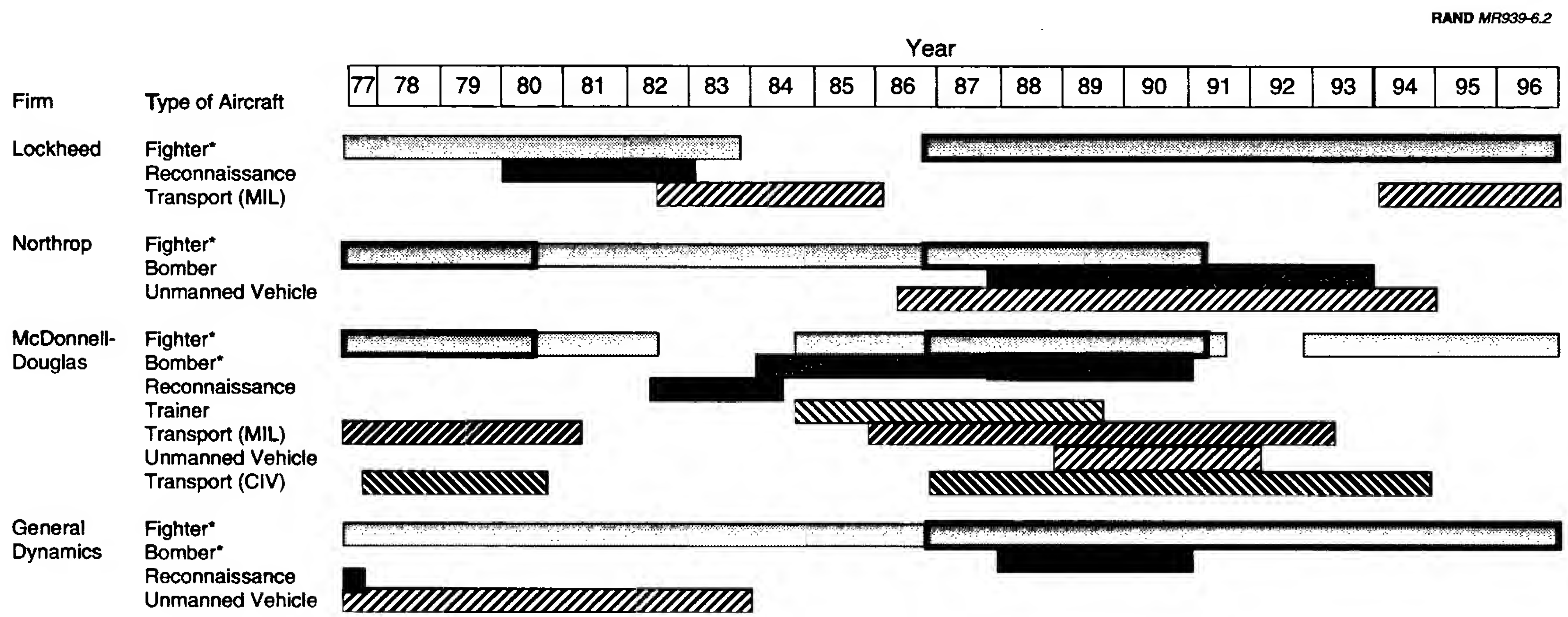
Photo 6.5—The Lockheed/Boeing F-22 Raptor is expected to be the premier Air Force air-superiority fighter of the early 21st century.

The A-12 experience illustrates the critical importance of firm-specific experience in stealth technologies beginning in the mid-1970s. However, the evidence suggests that system-specific experience still remained of great importance. By 1990, Northrop and Lockheed could arguably be labeled the industry leaders in fighter and bomber aircraft because of the combination of their extensive firm-specific expertise in stealth technologies and their unparalleled system-specific experience developing stealthy bombers and fighters. McDonnell-Douglas and General Dynamics can be considered to have slipped back somewhat from their leading positions in fighter development established during the previous period. This is largely due to their relative lack of firm-specific expertise in the early part of the period in certain technologies critical for stealth. Nonetheless, these two firms remained formidable competitors with their long history of fighter leadership and their development of such aircraft as the significantly upgraded F/A-18E, which included improved RCS characteristics, as well as involvement in the YF-22, YF-23, and A-12 programs.

As shown in Figure 6.2, these leaders in fighter R&D exhibited the same key characteristic of the leaders of the two earlier periods: Four of these contractors carried out an almost continuous stream of fighter R&D beginning in 1975. Boeing played a major role on the F-22 program and continued to compete vigorously for major military aircraft contracts; this experience is reflected in Figures 6.3 and 6.4. All other prime contractors, however, essentially exited from the fighter R&D business or were purchased by leading contractors. As was the case in the previous period, at least 40 percent of the total work days of all four leaders was devoted to ongoing development programs for fighter hardware, as shown in Figure 6.4. Boeing is also shown spending a comparable amount of time, because of its involvement with the F-22 program.

A wrenching consolidation and downsizing of the American aerospace industry began in the early 1990s after the collapse of the Berlin Wall and the end of the Cold War. In early 1993, Lockheed purchased General Dynamics' Ft. Worth fighter division, ending nearly half a century of independent combat aircraft R&D leadership dating back to Consolidated's B-24 Liberator and the Convair delta jets of the 1940s and 1950s. In mid-1994, Lockheed and Martin-Marietta agreed to merge, adopting the new name of Lockheed-Martin. In April 1994, Northrop purchased Grumman, ending the independent existence of the company that had been the Navy's premier fighter developer since the mid-1930s. At the same time, Northrop completed its purchase of LTV.[36] In 1996, Boeing bought Rockwell's aerospace and defense divisions, the core of what had been North American Rockwell, the developer of the first operational

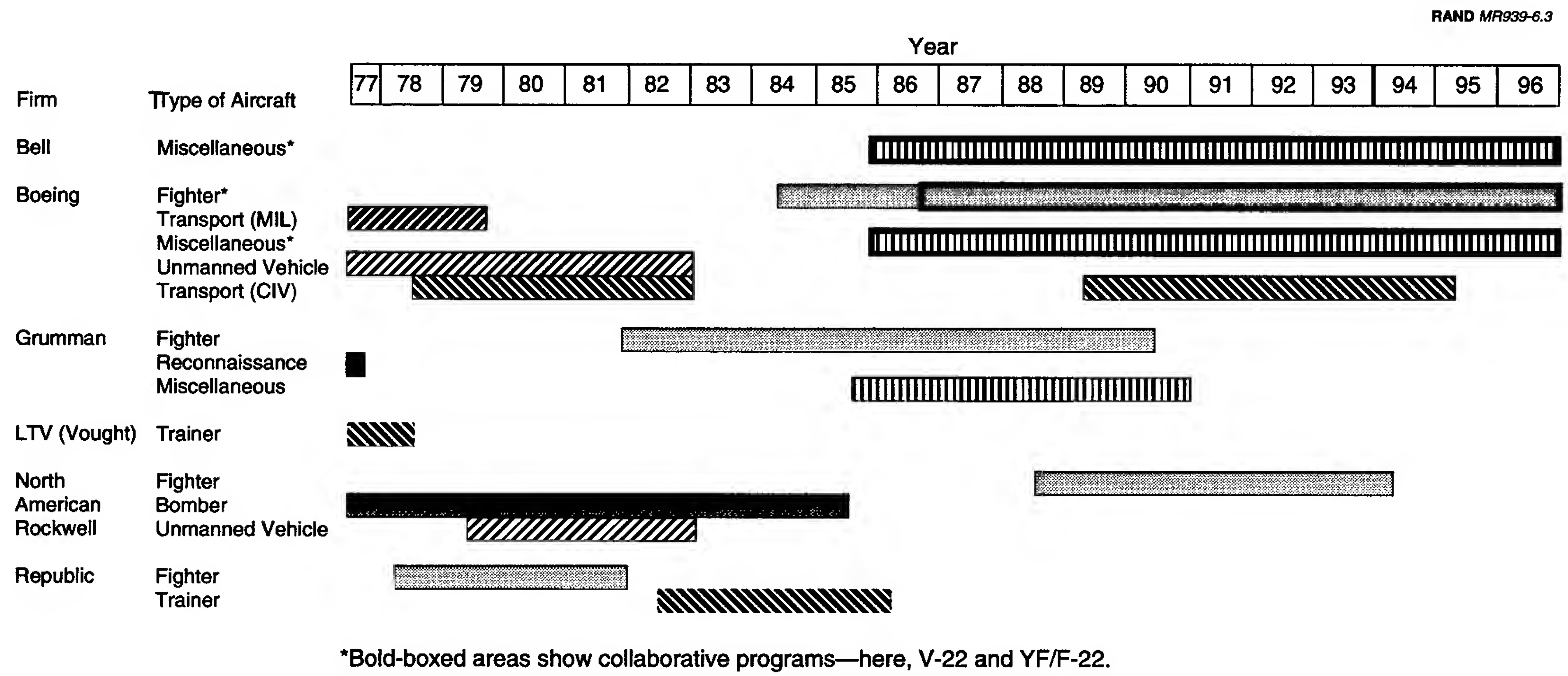
[36]Northrop had purchased a 49-percent interest in LTV in 1992.



*Bold-boxed areas show collaborative programs—here, A-12, F/A-18-A/B, YF/F-22, and YF-23.

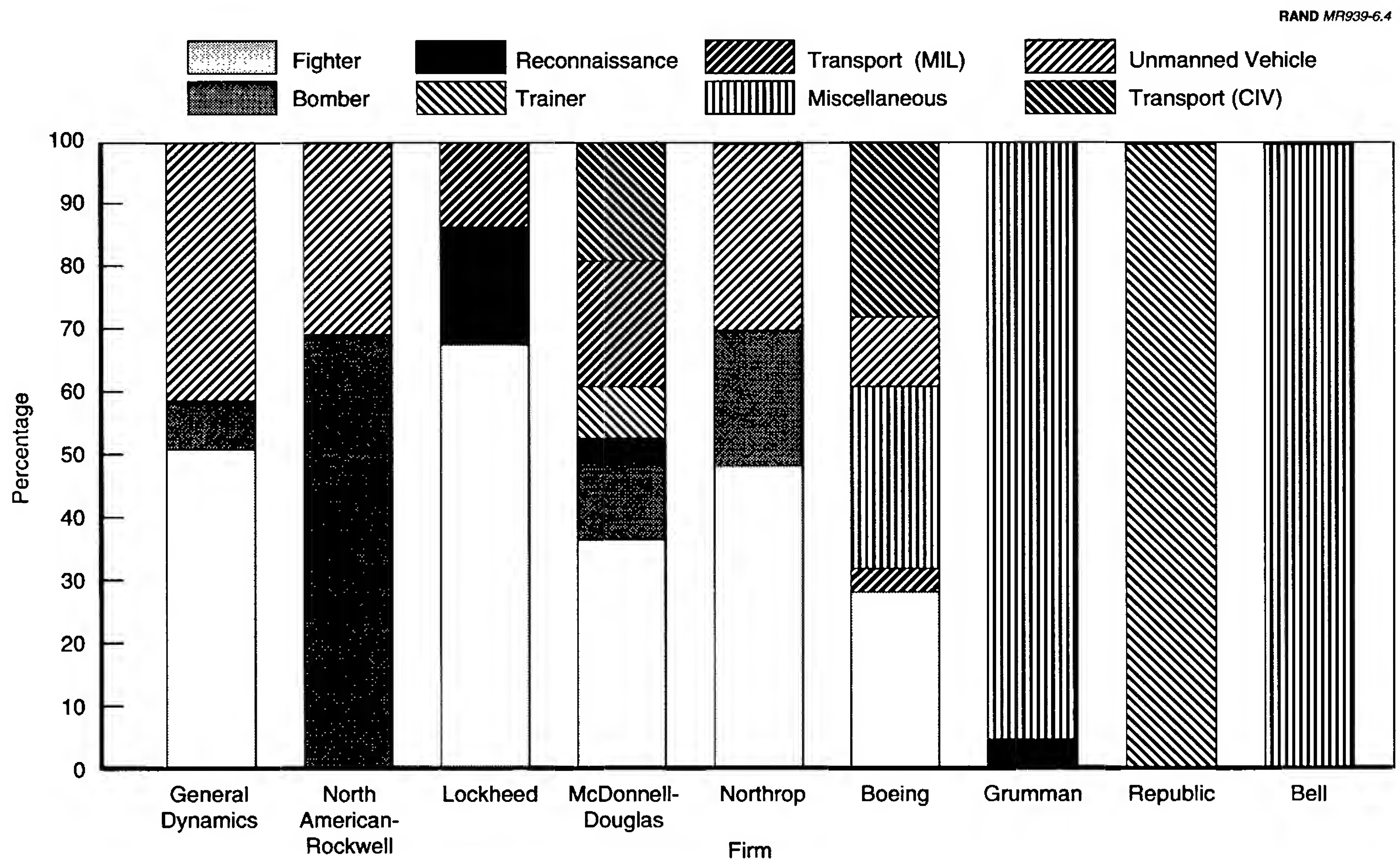
SOURCE: RAND database.

Figure 6.2—R&D Experience of Leading Fighter Developers in Period 3



SOURCE: RAND database.

Figure 6.3—R&D Experience of Other Prime Contractors in Period 3



SOURCE: RAND database.

Figure 6.4—Breakdown by Firm of Share of Experience by Types of Aircraft Relative to Firm's Total Experience in Period 3

supersonic fighter. Boeing followed this move almost immediately by announcing an even bigger move, a merger with its long-time rival, McDonnell-Douglas. Finally, in July 1997 Northrop-Grumman agreed to be acquired by Lockheed-Martin.[37]

Thus, in just over four years, five historic leaders in fighter R&D had been eliminated as independent entities: General Dynamics, Grumman, McDonnell-Douglas, Northrop, and Rockwell. The number of prime contractors with credible capabilities to develop new combat aircraft has been reduced from eight to just two: Lockheed-Martin and Boeing.

Germany and Great Britain pioneered the opening phases of the turbojet revolution in the 1940s, but the American aerospace industry almost single-handedly carried out an equally dramatic technological revolution in the 1970s and 1980s: stealth. In 1997, the remaining two leading American prime contractors in military aircraft R&D had attained a level of capability and experience in fighter and bomber development that far surpassed that possessed by any other national aerospace industry in the world. Yet the American industry also confronted the prospect of even fewer new R&D programs to maintain its experience base. What can the historical record tell us about the prospects for preserving the unparalleled experience base built up in the 1980s in the coming years in this constrained environment of declining defense budgets and few major new R&D programs?

[37]As of January 1998, the acquisition had yet to be formally approved.

Chapter Seven

CONCLUDING OBSERVATIONS

Great caution must be exercised in drawing definitive conclusions from the type of broad and general historical overview presented here. Nonetheless, the following observations based on the U.S. historical experience seem justified.

THE INTERPLAY OF EXPERIENCE AND INNOVATION

The central role of experience in ensuring the successful design and development of new jet fighters over the past five decades can be inferred from the tendency of aerospace prime contractors to specialize. Specialization came about because firms tended to develop competitive advantages in specific product areas by building up experience and focusing on R&D directly relevant to these areas. This experience resulted in system-specific capabilities—using the terminology of Hall and Johnson—that were not possessed by other leading contractors in the industry that had little experience with fighter R&D. This in turn made it more likely that the contractors with system-specific capabilities based on experience would win a new R&D competition in that specific area, which in turn resulted in such firms gaining even more experience and thus acquiring an even greater competitive edge.[1]

Yet unique firm-specific knowledge, particularly when related to key types of technology innovation, also appears to be a critically important concept for explaining the changes in leadership in the industry that take place during periods of great technological change. The evidence suggests that, particularly during periods of great technological change, firm-specific capabilities can be more important than system-specific capabilities. The historical record includes many instances of highly innovative firms that lacked significant system-specific experience in fighters and of firms with extensive system-specific

[1]Of course, one way for a firm to gain system-specific experience without participating in specific programs is to hire key individuals with such expertise. However, this still requires that there be sufficient programs (and sufficient other firms) to provide such expertise.

experience that lagged in technical innovation and the development of new firm-specific capabilities. In the end, both types of firms often fell from leadership positions or even exited entirely from the fighter R&D business. To maintain a position as an industry leader in fighters over the long run, it appears that successful prime contractors must combine both system-specific capabilities derived from extensive and continuous fighter R&D experience with unique and innovative firm-specific capabilities based on visionary technology research efforts.

Thus, both system- and firm-specific knowledge and capabilities appear to be highly relevant to the case of postwar fighter development and to help bring into relief the central importance of experience that arises from specialization within an industry.

THE IMPORTANCE OF SYSTEM-SPECIFIC EXPERIENCE

At the end of World War II, at least 14 prime contractors that developed fixed-wing military aircraft were competing for future government aircraft R&D programs. In all likelihood, virtually all these companies possessed the general industry-wide knowledge necessary to develop new fighter aircraft. Nonetheless, the most successful fighter developers of World War II—North American, Lockheed, and Republic for the Air Force, and Grumman for the Navy—immediately staked out leadership positions in the postwar race to develop effective first-generation jet fighters.

System-specific experience clearly played a central role in ensuring the successful design and development of advanced jet fighters over the past five decades. The leading fighter developers at the end of the Cold War—Lockheed, Northrop, McDonnell-Douglas, and General Dynamics—could boast of five decades of almost continuous experience developing fighters or fighterlike aircraft.

Lockheed, the developer of the innovative P-38 Lightning of World War II fame, pioneered jet-fighter R&D during the war with the P-80 Shooting Star. In the postwar decades, it continued its tradition of innovation with such aircraft as the F-104, SR-71/YF-12, D-21, F-117, and YF/F-22. Northrop followed up on the World War II success of its P-61 Black Widow with the F-89 Scorpion, the N-156/F-5/F-20 Freedom Fighter series, the YF-17, F/A-18, and YF-23. Following the development of numerous Navy and Air Force fighters in the 1940s and 1950s, McDonnell-Douglas became America's leading fighter developer in the 1960s and 1970s with the F-4, F-15, F-18, and AV-8B. General Dynamics' fighter R&D experience spanned the period of its supersonic deltas dating back to the XF-92 in the 1940s and the F-102/F-106 in the 1950s through the F-111 and the F-16 in more recent decades.

Yet none of these companies could be considered to have been dominant industry leaders throughout the entire post–World War II era. Indeed, by the late 1950s, Northrop and Lockheed had essentially withdrawn from the mainstream of fighter development into related specialized niche areas. In the 1950s, North American, Convair/General Dynamics, and Republic led in Air Force fighter R&D, while Grumman, McDonnell, and Vought provided leadership for the Navy. During the 1960s and 1970s, McDonnell-Douglas, General Dynamics, Grumman, and Northrop clearly predominated. Changing leadership patterns and the reemergence of Lockheed and Northrop during the late 1970s to mid-1990s indicate the pivotal importance of firm-specific knowledge and capabilities.

If experience is as important as might be inferred from the historical record, the DoD clearly needs to consider options that will help maintain experience levels during long periods when no major R&D programs are under way. Such a strategy could focus on prototyping or technology demonstration. However, other types of military R&D programs may also contribute considerably to maintaining fighter and bomber R&D capabilities.

THE EFFECT OF NEW TECHNOLOGY PARADIGMS

During the overall era under consideration, two periods of radical change in fighter technology took place: in the 1940s and 1950s with the introduction of jet propulsion, and in the 1970s and 1980s with the introduction of stealth. Revolutionary changes in technology may drastically shake up the current hierarchy of capabilities and skills in the aerospace industry. This is because companies with high system-specific capabilities have developed their skills on the old-technology aircraft, while other companies with eclectic firm-specific capabilities that may be highly relevant to the new types of aircraft may suddenly find themselves thrust into a leadership role.

It is widely recognized in the business world that the entry barriers into the aerospace industry are very high. This book argues that significant capability barriers exist that inhibit new entrants, especially during periods of normal technological evolution, and even make it difficult for a firm within the industry to change specialization and move into a new system area. A period characterized by a new technology paradigm, however, may drastically lower these intraindustry barriers.

One of the best examples of this phenomenon for the earlier period is McDonnell. In 1945, this company had no experience in developing an operational fighter or bomber, although the company had experimented during the war with unusual experimental prototypes. Grumman and Vought were the dominant developers of Navy fighters at the time. Yet in this period of dramatic

technological change, McDonnell succeeded in convincing the Navy that it possessed the new skills and capabilities necessary to develop jet fighters. Indeed, the Navy explicitly recognized that a hungry new company that was not wedded to any past approach might be the best type of contractor to take on the challenge of difficult new technologies. The St. Louis company went on to develop the Navy's first successful jet fighter, the FH-1 Phantom, and soon won an Air Force contract for another jet fighter. By the late 1950s, McDonnell had become the leading fighter developer for the Navy. Two decades later, it had become the leading fighter developer in America.

During the stealth period, the change in technology paradigms caused an even greater shake-up of leadership roles. Northrop and Lockheed had been relatively minor players in the area of conventional fighters and bombers since the late 1950s. They had ended up specializing in niche fighter-related areas: reconnaissance aircraft for Lockheed and lightweight export fighters for Northrop. But their unique firm-specific knowledge helped catapult them into leadership roles during the dawn of the stealth era. Lockheed was able to draw directly on its niche specialty in spy planes, which had long emphasized stealth. Northrop apparently drew on in-house study efforts launched in the 1960s. Gaining early entry into the stealth game, these two companies rapidly built up their firm-specific and system-specific capability advantages. Exploiting their unique positions, these companies were able to move ahead of the dominant leaders in conventional fighters and bombers from the 1960s and 1970s: McDonnell-Douglas, General Dynamics, and Rockwell.

This situation seems to suggest that system-specific experience may count considerably less in periods of dramatic technological change. But it is difficult to predict when these periods will take place and what firm-specific skills will suddenly be more important. This may imply, however, that it is important to support a significant number of companies—or at least divisions—engaged in a wide variety of different specializations and system-specific development. Northrop kept itself alive in the 1960s and 1970s in part through its own efforts to develop and sell an export fighter. After failing to win any major U.S. military aircraft development programs, it could have just as easily withdrawn from the prime contract market, as Martin and LTV had. Likewise, Lockheed failed to win any significant conventional fighter or bomber contracts for more than two decades after the F-104. Lockheed would not have developed its unique expertise without its highly specialized niche area of spy planes dating back to the 1950s.

In short, the dramatic downsizing and consolidation of the aerospace industry currently under way may have serious unanticipated long-term technology consequences if aggressive and entrepreneurial niche companies can no longer be maintained as in the past.

THE RELATIONSHIP OF FIGHTER R&D TO OTHER TYPES OF SYSTEM DEVELOPMENT

The historical record indicates that successful fighter development is aided by system-specific capabilities based on experience. As suggested above, firm-specific capabilities also appear to have been particularly important, especially in the 1950s and during the stealth era in the 1970s and 1980s.

Overall since the 1940s, companies that combine system-specific fighter R&D capabilities with critical firm-specific capabilities—the latter often related to combat aircraft development—seem to have done particularly well. On the other hand, expertise in large commercial or military transports does not appear to be as relevant as bombers, attack aircraft, and other combat aircraft for fighter development. This is because the specific technical challenges that developers of modern fighters confront have grown increasingly different from those that developers of airliners face. Fighters are small, densely packed, very-high-performance aircraft optimized for agility, maneuverability, survivability, and stealthiness. Commercial transports are large, relatively slow aircraft optimized for safety and economic efficiency in hauling passengers and freight.

Indeed, historically, there almost appears to be an inverse correlation between success in fighters and large commercial transport aircraft. Boeing has long been a leader in commercial transport development but stopped developing new bomber designs after the early 1950s and has not won a fighter R&D contract since World War II.[2] Convair/General Dynamics made a strong bid for commercial jet-transport leadership in the 1950s, but failed. North American was never a key player in large commercial transports, but was a prominent fighter developer well into the 1960s. Although Rockwell never won a fighter contract after the cancellation of the F-108, it continued to maintain a major fighter design and development capability and vigorously competed for nearly all fighter contracts well into the 1980s. In the 1970s and 1980s, it was involved in two major fighter technology-demonstration programs that included flying prototypes: HiMAT and X-31. Lockheed, the current leader in Air Force fighter R&D, withdrew from the commercial transport market in the 1970s after the costly commercial failure of its L-1011 wide body in competition with the DC-10 and Boeing 747. The commercial Douglas division of McDonnell-Douglas has struggled to make a profit ever since it merged with the St. Louis company. Finally, Northrop has never been a developer of large commercial transport designs.

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[2]This may be changing in the new post–Cold War environment. Boeing is a very serious contender for the Joint Strike Fighter (JSF) program. In addition, Boeing fighter design proposals have always fared quite well in past fighter competitions. Boeing now has also acquired additional expertise through the merger with McDonnell-Douglas.

The historical record suggests that, in the future, many firm-specific skills and capabilities related to fighter development may be maintained through other types of high-performance military aircraft programs, such as reconnaissance aircraft, bombers, and attack aircraft. On the other hand, commercial and military transport development does not appear to be as closely correlated to success in fighter R&D—at least not historically.

THE IMPORTANCE OF GOVERNMENT MILITARY TECHNOLOGY RESEARCH

A final observation that emerges from the historical record is the importance of basic and applied research funded by the government and performed in both government labs and industry. At various times over the past 50 years, key technological breakthroughs that (at least at the time they were performed) were uniquely applicable to military applications emerged from Air Force and NASA labs and the industry teams they supported. This seems to be particularly true during periods of revolutionary technological change, such as in the 1940s and 1950s and the 1970s and 1980s.

For the first period, some of the basic science that permitted supersonic flight was developed through the X-plane programs and associated activities in government labs. Much of the critical ground-breaking aerodynamic and propulsion research that made supersonic flight possible, as well as such technology as the variable-geometry wings later used on the F-111 and F-14, were made possible through theoretical and hardware advances achieved by government researchers and contractors working with them.

As revealed only recently, much of the basic science and technology that made genuinely stealthy combat aircraft possible was generated through a sustained program of research in both government and industry labs in the 1950s and 1960s. In a like manner, technological breakthroughs covering the spectrum from active phased-array radars to thrust vectoring and new materials were achieved through sustained government support of basic and applied research focused on military applications.

These observations suggest that a heavier dependence on technology development in the commercial sector and further cutbacks in government-funded science and technology may be risky for future military aircraft development. The importance of such "dual-use" technology, except possibly in electronics and on the parts level, may be exaggerated. The basic methodologies and technologies behind radical new developments in military capabilities ranging from stealth to supermaneuverability are unlikely to have ever emerged from the commercial marketplace. In any event, dual-use technology does not constitute a substitute for fighter R&D experience on the system level.

COMPETITION AND CAPABILITIES

During World War II, Britain and Germany's numerous military aircraft developers led the world in fighter R&D. Through the 1950s, these two countries, as well as France, each continued to maintain multiple firms that competed fiercely for combat-aircraft development contracts. Many of these firms produced world-class fighters, such as the Dassault Mirage III, or the English Electric Lightning. By the late 1960s and early 1970s, however, Europe's national industries had been forced to consolidate to the point at which only a single firm remained in each country that was truly capable of developing competitive combat aircraft. From this point on, European combat aircraft technology tended to fall behind comparable U.S. technology, especially in the areas of avionics, stealth, and propulsion. From the 1970s on, American companies pioneered the stealth revolution. European companies had barely begun to investigate first-generation stealth technologies seriously when their U.S. counterparts were already involved in second- and third-generation developments.

Although it is true that U.S. industry has historically enjoyed much higher military R&D funding levels than its European counterparts, it also seems plausible that the U.S. military services have benefited from the intense competition among many innovative firms. Again, the roles Northrop and Lockheed played during the early days of the stealth revolution, as well as McDonnell at the beginning of the jet era, are instructive. Every major U.S. fighter contract from the F-111 on has had six to eight serious competitors, each fiercely fighting to win through exploitation of the most innovative and effective technologies and design approaches. The ultimate prize is potentially so lucrative that even such companies as Boeing and Rockwell—which had not won a fighter contract for decades—continued to invest significant corporate resources in maintaining and improving their fighter design and technology capabilities. Clearly, at least some important part of the great historic success of American fighter developers can be attributed to the extraordinary competition among significant numbers of players.

If this is true, U.S. defense planners should be concerned about the continuing consolidation of the U.S. industry. In 1995, the Joint Strike Fighter (JSF) program remained the only likely new combat aircraft R&D program on the horizon for many decades to come. Reminiscent of McNamara's TFX proposal, the JSF requirement attempts simultaneously to satisfy the Navy requirement for a stealthy attack fighter to replace the A-6 and F-14, the Air Force requirement for an F-16 replacement, and a Marine requirement for a V/STOL replacement for the Harrier. The Pentagon intends to pick one aircraft design to satisfy all three services, hoping for about 80-percent commonality among the three service versions. The two groups led by Lockheed-Martin and Boeing are competing

with perhaps unprecedented intensity to win the JSF competition. To remain a viable and credible developer of fighters in the future, each contractor group believes it has to win the competition. Both teams know that, in the words of one observer, "the losers may find themselves out of the business of making military planes."[3]

In short, the two remaining American fighter prime contractors approach the 21st century with an unprecedented level of capabilities and experience in fighter and bomber development. Yet American industry also confronts the possibility of having just one prime contractor continuing to build on its experience base with new fighter R&D programs through the next several decades. Such a situation may ultimately lead to a squandering of the 50 years of U.S. leadership in fighter R&D. Defense planners need to continue considering innovative strategies for maintaining the U.S. experience base in the post–Cold War environment through competitive prototype and technology-demonstration programs, further acquisition reform, greater use of best commercial practices, and other approaches.

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[3]U.S. House of Representatives (1992a), p. 186.

Appendix A

DATABASE DESCRIPTION

To support the analysis presented in this book, we developed a database that is, to the best knowledge of the authors, the most comprehensive of its kind ever published. It was developed in the context of continuous research at RAND on historical trends in acquisition patterns, procedures, and processes.[1] The database contains descriptive, historical, and numerical information on most fixed-wing and related military and commercial aircraft R&D programs undertaken by U.S. aerospace contractors after World War II.

R&D programs are divided into eight categories, by types of aircraft. The R&D experience has been divided into five distinct phases that are both analytically distinct and tractable. We make the distinction between a "record" and a "program." A record is any aircraft version for which the authors could identify, with reasonable certainty, beginning and completion dates for at least one of the different phases of development. A program is any record for which we could identify at least one of the three core phases of development: technology demonstrator or prototype (TD/PROTO), full-scale development (FSD) or X-plane (X) development.[2] Such a distinction between record and program is necessary for two reasons. First and most importantly, each phase of experience is fundamentally different from the other phases. Second, historical data on the three core phases of development are much more complete and reliable than those of either the design (DESIGN) or the model upgrade (UPGRADE) phase.[3]

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[1]See, in particular, Smith and Friedmann (1980).

[2]X-plane experience is treated as a separate category, while X-planes are not treated as a separate type of aircraft. Indeed, X-plane development is treated as a separate development phase for two reasons. First, typically, X-plane programs focus on very specific technologies like supersonic flight or atmospheric reentry. Second, X-planes are not designed to meet any specific military mission requirement. For example, they are not equipped with such items as bomb bays or fire-control radars. Depending on the contribution of the technology under investigation, we have categorized X planes by aircraft type. For example, the X-1 is treated as a fighter because it is a fighterlike aircraft whose focus is on enhanced fighter maneuverability.

[3]The design phase covers conceptual design work done prior to FSD. It does not include the design work done during FSD, which falls under that phase.

STRUCTURE

There are three parts to the database: (1) descriptive, (2) historical, and (3) numerical. The descriptive part comprises nine fields: the aircraft designation (three fields), the firm developing and producing the aircraft,[4] the name of the aircraft, whether it is supersonic or not, what service procured the aircraft and, finally, the first flight date. The second part of the database comprises historical data, which will be discussed in the next section. Finally, the database has numerical data on the working days of the time taken at each phase of the developmental process.[5] The sources of the database are the public sources listed in the bibliography.

PHASES OF DEVELOPMENT

With development programs lasting several years, it is necessary to break out the long and varied developmental effort into distinct phases corresponding to different stages of development and, hence, of experience. Such a breakdown is necessary to avoid aggregating fundamentally different types of experience. For example, the level of effort, numbers and types of people, and resources used for conducting preliminary design work are unique to this task and are significantly different from the resources the same firm would expend in the case of an FSD effort.

We decided to use the same basic benchmarks of development effort that Giles Smith and Ellen Friedmann used in prior RAND research.[6] The acquisition cycle can be divided into three phases: planning, development, and production. This book focuses on the first two phases. The distinction between these two phases has varied over time. Smith and Friedmann have identified significant variations in these definitions during different periods: the 1950s, 1960s, and 1970s, which roughly correspond to our Periods 1, 2, and 3.

The first period was characterized by the absence of formal acquisition policy, because "the Secretary of Defense did not have the authority to enforce such a policy. [T]he individual services ran their own acquisition programs." (p. 2)

The second period was the McNamara era, during which, in essence, power was centralized and decisionmaking was concentrated within OSD. The major departure from the previous period was the increased reliance on paper studies instead of prototyping. The acquisition phase was divided into three sub-

[4]The only noticeable exception is the B-57, produced by Martin but based on a design developed by the British firm English Electric.

[5]These data are not included in Appendix B, but are available from the authors.

[6]Smith and Friedmann (1980). We briefly summarize pp. 2–6 here.

phases: two planning phases and one acquisition phase, which included today's FSD and production phases.

The third period followed policies developed by David Packard, deputy of then–Secretary of Defense Melvin Laird. It centered on the 1971 Directive 5000.1, *Acquisition of Major Defense Systems.* In this directive, Packard segmented the acquisition cycle into three major milestones, which are decision points separating the different phases of development:

- Milestone I: Beginning of concept dem/val
- Milestone II: Beginning of FSD
- Milestone III: Beginning of high-rate production.

Once a milestone was completed, the Secretary of Defense would review the program and decide whether it could move on to the next phase or not.

Current acquisition policy is very similar to that introduced by Packard. It is still based on the segmentation of acquisition policy into major milestones. The current policy is contained in Directives 5000.1 and 5000.2 (February 23, 1991).[7] There are now five major acquisition milestones and five phases:

- Milestone 0: Concept studies approval
- Milestone I: Concept demonstration approval
- Milestone II: Development approval
- Milestone III: Production approval
- Milestone IV: Major modification approval.

The intervening phases are:

- Phase 0: Concept exploration and definition
- Phase I: Dem/val
- Phase II: Engineering and manufacturing development (EMD)
- Phase III: Production and deployment
- Phase IV: Operations and support.

In our database, we have divided "experience" into different categories of experience:

[7] A major revision appeared in early 1996.

- DESIGN: Corresponding to phase 0
- TD/PROTO: Corresponding to phase I
- FSD: Corresponding to phase II
- UPGRADES: Corresponding to the phase of development after milestone IV
- X: Corresponding to phases I and II, applied to the development of X-planes.

QUANTITATIVE APPROACH

The size of a phase in this database is the number of days spent working on a program. The number of working days is an indirect measure of the number of people involved and the amount of resources allocated to a program. We have tried to account for intrinsic differences by segmenting the data into different types of aircraft and different phases of development and by restricting the analysis of the data to individual periods, without intertemporal comparisons.

The choice of number of days worked on a program as a proxy for experience was dictated by the fact that no other measure was as satisfactory. Indeed, there are mainly two types of other data that could be used to measure experience: dollars expended or number of persons working on a given program. However, cost data are difficult to standardize across periods, firms, programs, and R&D phases. There is tremendous uncertainty about what the total cost of a program is and how much of the research conducted outside the program should be associated with it.

The number of people involved in the program at any given phase of development is a better measure of experience. However, there is great diversity in the skills of people involved. Thus, this measure could be meaningfully used only with a breakdown by skills of the people involved in the program. Except for the most recent past, such data are even more difficult to find and reconcile than are cost data.

Given the limitations of these two measures, we decided to use the number of days worked on a program as a proxy for experience. This measure has its own limitations. Three of them stand out. First, different types of aircraft require different development times. Second, different acquisition environments shift the boundaries of the phases of development. Third, there are various levels of intensity of work in the development of an aircraft, depending on the urgency attached to its development.

We minimized the problems associated with the first two limitations as much as possible by categorizing aircraft and by limiting our analysis to each time

period. We did not aggregate data for different types of aircraft or across time periods. The third limitation, however, could not be avoided. Some programs were placed on compressed high-priority schedules, while others progressed very slowly over much longer periods. This problem could not be solved in the database. Only the qualitative historical analysis helps identify and correct for such differences.

The attached database covers five decades of aircraft development in the United States. It offers what we believe is the best set of data available from published sources spanning these five decades of development. Two aspects of the database are noteworthy. First, the U.S. military aerospace industry has been extremely prolific in both the number of aircraft developed and the diversity of aircraft developed during this time. Second, the data are characterized both by homogeneity and diversity: homogeneity stemming from the impressive continuity in supply by the same prime contractors (though their number declined over time) and diversity in demand stemming from the changing politico-strategic and regulatory environments in which design and development—and eventually procurement—took place.

Some of the data are spotty. Two sources of bias were introduced at the stage of data collection. First, inclusion into the database was dictated by data availability. This availability was not equally distributed across manufacturers, types of aircraft, and development phases. Indeed, the activities of some firms are systematically better documented than others. Also, data are more precise for, say, fighters than for reconnaissance aircraft. In addition, design and upgrade phases of development typically have less-complete historical data. Finally, Air Force aircraft are better represented than are Navy or Marine Corps aircraft.

Second, because the focus of this book is on fighter development and that of the companion report is on bombers, the data are most complete for these two categories of aircraft. Virtually every model of these two types of aircraft was included unless data was truly unavailable (as was the case for some upgrade models). As for the other aircraft categories, data were most complete for military aircraft and unmanned vehicles (cruise missiles and unmanned aircraft) but less so for commercial aircraft.

Appendix B

DATABASE

Aircraft	Suffix	Firm	Name	Type	Sonic	Service	1st Flight
X-1	A/B/C/D	Bell		Fighter	Super	AF/ NACA	07-51
X-1	E	Bell		Fighter	Super	AF/ NACA	12-55
X-1		Bell		Fighter	Super	AF/ NACA	04-47
X-14	A, B	Bell		Fighter	Sub	AF	02-57
X-16		Bell	Bald Eagle	Reconnaissance	Sub	AF/ CIA	
X-2		Bell		Fighter	Sub	AF/ NACA	06-52
X-5		Bell		Fighter	Sub	AF/ NACA	06-51
X-9		Bell	(MX-771A) Shrike	Unmanned vehicle	Super	AF	05-50
V-22		Bell/ Boeing	Osprey	Miscellaneous	Sub	NV	03-89
367-80		Boeing	Dash Eighty	Transport (Civilian)	Sub	—	07-54
707/720		Boeing		Transport (Civilian)	Sub	—	12-57
727		Boeing		Transport (Civilian)	Sub	—	02-63
737		Boeing		Transport (Civilian)	Sub	—	04-67
747		Boeing		Transport (Civilian)	Sub	—	02-69
757		Boeing		Transport (Civilian)	Sub	—	02-82
767		Boeing		Transport (Civilian)	Sub	—	09-81
777		Boeing		Transport (Civilian)	Sub	—	06-94
A-6	F	Boeing	Intruder	Fighter	Sub	Navy	08-87
AGM-86	A	Boeing	ALCM-A	Unmanned vehicle	Sub	AF	03-76
AGM-86	B	Boeing	ALCM-B	Unmanned vehicle	Sub	AF	08-79
B-47	A	Boeing	Stratojet	Bomber	Sub	AF	06-50
B-47	B	Boeing	Stratojet	Bomber	Sub	AF	02-51
B-47	E	Boeing	Stratojet	Bomber	Sub	AF	01-53

Aircraft	Suffix	Design		TD/Prototype		FSD		Upgrade		X-Plane	
		Start	End	Start	End	Start	End	Start	End	Start	End
X-1	A/B/C/D	11-47	03-48							04-48	04-53
X-1	E									04-52	09-58
X-1		12-43	02-45							03-45	05-47
X-14	A, B	02-52	06-55							07-55	02-57
X-16		07-53	12-53							01-54	11-54
X-2		10-45	11-45							12-45	09-56
X-5		02-49	06-49							07-49	10-51
X-9		04-46	12-47							01-48	06-52
V-22		04-85	12-85			01-86	12-96				
367-80		01-50	04-52	05-52	07-54						
707/720						05-52	12-58				
727		04-59	09-60			12-60	12-63				
737		11-64	01-65			02-65	12-67				
747		01-65	03-66			04-66	12-69				
757						08-78	12-82				
767						07-78	07-82				
777						06-89	04-95				
A-6	F					06-84	07-88				
AGM-86	A	02-74	11-74	12-74	06-77						
AGM-86	B			07-77	02-80	03-80	12-82				
B-47	A					09-48	12-50				
B-47	B							09-48	10-52		
B-47	E							01-53	04-53		

Aircraft	Suffix	Firm	Name	Type	Sonic	Service	1st Flight
B-47		Boeing	Stratojet	Bomber	Sub	AF	12-47
B-50		Boeing	B-29D Superfortress	Bomber	Sub	AF	06-47
B-52	A	Boeing	Stratofortress	Bomber	Sub	AF	08-54
B-52	B	Boeing	Stratofortress	Bomber	Sub	AF	12-54
B-52	C	Boeing	Stratofortress	Bomber	Sub	AF	03-56
B-52	D	Boeing	Stratofortress	Bomber	Sub	AF	06-56
B-52	E	Boeing	Stratofortress	Bomber	Sub	AF	10-57
B-52	F	Boeing	Stratofortress	Bomber	Sub	AF	05-58
B-52	G	Boeing	Stratofortress	Bomber	Sub	AF	02-59
B-52	H	Boeing	Stratofortress	Bomber	Sub	AF	07-60
B-52		Boeing	Stratofortress	Bomber	Sub	AF	04-52
B-54	A	Boeing		Bomber	Sub	AF	
KC-135	A	Boeing	Stratotanker	Transport (Military)	Sub	AF	08-56
C-135	A	Boeing		Transport (Military)	Sub	AF	05-61
E-3	A	Boeing	Sentry (AWACS)	Miscellaneous	Sub	—	06-75
E-767		Boeing		Miscellaneous	Sub	—	08-96
IM-99	A	Boeing	Bomarc	Unmanned vehicle	Super	AF	08-54
XB-59		Boeing		Bomber	Super	AF	
YC-14		Boeing		Transport (Military)	Sub	AF	08-76
880		Convair		Transport (Civilian)	Sub	—	01-59
990		Convair		Transport (Civilian)	Sub	—	01-61
B-36	A	Convair	Peacemaker	Bomber	Sub	AF	08-46
B-36	B	Convair	Peacemaker	Bomber	Sub	AF	07-48

Aircraft	Suffix	Design		TD/Prototype		FSD		Upgrade		X-Plane	
		Start	End	Start	End	Start	End	Start	End	Start	End
B-47		09-43	11-44	12-44	08-48						
B-50						12-45	03-49				
B-52	A					02-51	06-55				
B-52	B							02-51	06-55		
B-52	C							12-53	06-56		
B-52	D							08-54	12-56		
B-52	E							10-55	12-57		
B-52	F							11-54	06-58		
B-52	G							06-56	02-59		
B-52	H							01-59	06-61		
B-52		04-45	06-48	07-48	01-51						
B-54	A	04-47	04-48			05-48	04-49				
KC-135	A					10-54	06-57				
C-135	A							02-61	06-61		
E-3	A					01-73	03-77				
E-767						12-92	01-98				
IM-99	A	05-50	12-50			01-51	09-59				
XB-59		01-46	01-48								
YC-14		01-72	10-72	11-72	08-79						
880		01-55	03-56			04-56	05-60				
990		01-58	06-58			07-58	12-61				
B-36	A					01-44	08-47				
B-36	B							09-47	11-48		

Aircraft	Suffix	Firm	Name	Type	Sonic	Service	1st Flight
B-36	D	Convair	Peacemaker	Bomber	Sub	AF	07-49
RB-36	D, RB-36D	Convair	Peacemaker	Reconnaissance	Sub	AF	12-49
B-36	F	Convair	Peacemaker	Bomber	Sub	AF	11-50
B-36	H	Convair	Peacemaker	Bomber	Sub	AF	11-50
C-131	A/B	Convair	Samaritan	Transport (Military)	Sub	AF	05-50
F-102	A	Convair	Delta Dagger	Fighter	Super	AF	10-53
TF-102	A	Convair	Delta Dagger	Trainer	Sub	AF	11-55
F-106	A	Convair	Delta Dart	Fighter	Super	AF	12-56
F-106	B	Convair	Delta Dart	Fighter	Super	AF	09-58
R3Y	1/2	Convair	Tradewind	Transport (Military)	Sub	Navy	02-54
T-29	A	Convair		Trainer	Sub	AF	09-49
XB-46		Convair		Bomber	Sub	AF	04-47
XB-53		Convair		Bomber	Sub	AF	
XC-99		Convair		Transport (Military)	Sub	AF	11-47
XF-92A		Convair		Fighter	Super	AF	09-49
XF2Y-1		Convair	Sea Dart	Fighter	Sub	Navy	04-53
XFY-1		Convair	Pogo	Miscellaneous	Sub	Navy	08-54
XP-81		Convair		Fighter	Sub	AF	03-45
YB-60		Convair	(B-36G)	Bomber	Sub	AF	04-52
B-58		Convair GD	Hustler	Bomber	Super	AF	11-56
BGM-109	A	Convair GD	Tomahawk (R/U GM-109)	Unmanned vehicle	Sub	Navy	03-76
BGM-109	B	Convair GD	TASM (R/U GM-109)	Unmanned vehicle	Sub	Navy	12-76
BGM-109	G	Convair GD	Gryphon (GLCM)	Unmanned vehicle	Sub	AF	05-80

Aircraft	Suffix	Design		TD/Prototype		FSD		Upgrade		X-Plane	
		Start	End	Start	End	Start	End	Start	End	Start	End
B-36	D							03-49	12-50		
RB-36	D, RB-36D							03-49	06-51		
B-36	F							11-50	03-51		
B-36	H							11-50	12-51		
C-131	A/B							04-50	03-54		
F-102	A	10-48	01-51			02-51	04-56				
TF-102	A							04-52	11-55		
F-106	A	01-49	11-51			12-51	05-59				
F-106	B							08-56	07-60		
R3Y	1/2					05-50	02-54				
T-29	A					10-49	02-50				
XB-46				01-44	08-47						
XB-53		01-46	01-48								
XC-99				01-44	05-49						
XF-92A				06-48	10-49						
XF2Y-1				10-48	05-55						
XFY-1				07-52	06-55						
XP-81				01-44	03-45						
YB-60				08-50	08-52						
B-58		10-46	01-51			02-51	08-59				
BGM-109	A			12-73	02-76	03-76	03-83				
BGM-109	B					03-76	06-82				
BGM-109	G					01-77	12-83				

Aircraft	Suffix	Firm	Name	Type	Sonic	Service	1st Flight
F-111	C	Convair GD		Fighter	Super	AF	
F-111	D	Convair GD		Fighter	Super	AF	05-70
F-111	E	Convair GD		Fighter	Super	AF	08-69
F-111	F	Convair GD		Fighter	Super	AF	09-71
F-16	A	Convair GD	Fighting Falcon	Fighter	Super	AF	08-78
F-16	B	Convair GD	Fighting Falcon	Fighter	Super	AF	12-78
F-16	C	Convair GD	Fighting Falcon	Fighter	Super	AF	06-84
YF-16	CCV	Convair GD	CCV	Fighter	Super	AF	03-76
F-16	D	Convair GD	Fighting Falcon	Fighter	Super	AF	09-84
NF-16	D	Convair GD	Vista	Fighter	Super	AF	09-92
F-16	N	Convair GD	Fighting Falcon	Fighter	Super	Navy	06-84
F-16	XL	Convair GD	S.C.A.M.P	Fighter	Super	AF	07-82
YF-16		Convair GD		Fighter	Super	AF	01-74
AFTI F-16		Convair GD	AFTI	Fighter	Super	AF	07-82
F-111	A	Convair GD/ Grumman		Fighter	Super	AF	02-67
F-111		Convair GD/ Grumman		Fighter	Super	AF	12-64
FB-111	A	Convair GD/ Grumman		Bomber	Super	AF	07-67
XF-87		Curtis		Fighter	Sub	AF	03-48
XF15C		Curtis		Fighter	Sub	AF	02-45
A-1	AD	Douglas	Skyraider	Fighter	Sub	Navy	03-45
A-1	AD-1	Douglas	Skyraider	Fighter	Sub	Navy	11-46
A-1	AD-5	Douglas	A-1E, Skyraider	Fighter	Sub	Navy	08-51
A-3	A	Douglas	Skywarrior	Fighter	Sub	Navy	09-53

Aircraft	Suffix	Design		TD/Prototype		FSD		Upgrade		X-Plane	
		Start	End	Start	End	Start	End	Start	End	Start	End
F-111	C							10-63	09-68		
F-111	D							05-67	07-71		
F-111	E							02-68	08-69		
F-111	F							07-70	09-71		
F-16	A					01-75	12-76				
F-16	B							01-75	12-78		
F-16	C							12-82	07-84		
YF-16	CCV			06-77	07-78						
F-16	D							12-82	09-84		
NF-16	D			12-88	11-93						
F-16	N							01-85	06-87		
F-16	XL	12-80	02-81	03-81	05-83						
YF-16		01-72	03-72	04-72	12-74						
AFTI F-16				12-78	12-91						
F-111	A					04-65	04-67				
F-111		09-61	11-62	12-62	03-65						
FB-111	A					05-64	10-69				
XF-87				01-46	10-48						
XF15C				04-44	10-46						
A-1	AD					07-44	04-45				
A-1	AD-1							05-45	11-46		
A-1	AD-5							10-50	08-51		
A-3	A					11-52	09-53				

Aircraft	Suffix	Firm	Name	Type	Sonic	Service	1st Flight
XA-3		Douglas	Skywarrior	Fighter	Sub	Navy	10-52
A-4	A	Douglas	A4D, Skyhawk	Fighter	Sub	Navy	08-54
TA-4	E	Douglas	A4D, Skyhawk	Trainer	Sub	Navy	06-65
XA-4		Douglas	XA4D-1, Skyhawk	Fighter	Sub	Navy	06-54
A2D-1		Douglas	Skyshark	Fighter	Sub	Navy	05-50
RB-66	A	Douglas	Destroyer	Reconnaissance	Sub	AF	06-54
B-66	B	Douglas	Destroyer	Bomber	Sub	AF	01-55
C-124	A	Douglas	Globemaster II	Transport (Military)	Sub	AF	11-49
YC-124	B	Douglas	Globemaster II	Transport (Military)	Sub	AF	02-54
C-132		Douglas		Transport (Military)	Sub	AF	
C-133	A	Douglas	Cargomaster	Transport (Military)	Sub	AF	04-56
C-74		Douglas	Globemaster I	Transport (Military)	Sub	AF	09-45
D-558-1		Douglas	Skystreak	Fighter	Sub	NV/ NACA	04-47
D-558-2		Douglas	Skyrocket	Fighter	Super	NV/ NACA	02-48
DC-8	Super 60	Douglas		Transport (Civilian)	Sub	—	03-66
DC-8		Douglas		Transport (Civilian)	Sub	—	05-58
DC-9		Douglas		Transport (Civilian)	Sub	—	02-65
F-10	A	Douglas	F3D-1, Skyknight	Fighter	Sub	Navy	02-50
F-10	B	Douglas	F3D-2, Skyknight	Fighter	Sub	Navy	02-51
XF-10		Douglas	XF3D-1, Skyknight	Fighter	Sub	Navy	03-48
F-6		Douglas	F4D, Skyray	Fighter	Super	Navy	01-51
F5D-1		Douglas	Skylancer	Fighter	Super	Navy	04-56
X-3		Douglas	Stiletto	Fighter	Super	AF/ NACA	10-52

Aircraft	Suffix	Design		TD/Prototype		FSD		Upgrade		X-Plane	
		Start	End	Start	End	Start	End	Start	End	Start	End
XA-3		03-47	02-49	03-49	10-52						
A-4	A					10-52	08-54				
TA-4	E							06-64	06-65		
XA-4		01-52	06-52	07-52	06-54						
A2D-1		06-45	08-47	09-47	08-54						
RB-66	A					02-52	06-54				
B-66	B							09-52	01-55		
C-124	A					09-45	05-50				
YC-124	B			01-51	10-56						
C-132		01-51	01-56								
C-133	A					02-53	04-56				
C-74		01-42	05-42			06-42	01-46				
D-558-1		02-45	06-45	07-45	04-49						
D-558-2				01-46	08-51						
DC-8	Super 60							04-65	09-66		
DC-8						06-55	08-59				
DC-9		01-62	03-63			04-63	11-65				
F-10	A					06-48	10-50				
F-10	B							08-49	02-51		
XF-10		03-46	03-48	04-46	10-48						
F-6		06-47	11-48			12-48	06-54				
F5D-1						03-53	04-56				
X-3		12-43	05-45							06-45	07-53

Aircraft	Suffix	Firm	Name	Type	Sonic	Service	1st Flight
XB-42		Douglas	Mixmaster	Bomber	Sub	AF	05-44
XB-43		Douglas		Bomber	Sub	AF	05-46
A-6	A	Grumman	A2F Intruder	Fighter	Sub	Navy	04-60
EA-6	A	Grumman	Prowler	Reconnaissance	Sub	Marine Corps	04-63
EA-6	B	Grumman	Prowler	Reconnaissance	Sub	Navy	05-68
A-6	C	Grumman	Intruder	Fighter	Sub	Navy	12-68
A-6	E	Grumman	Intruder	Fighter	Sub	Navy	02-70
AO-1		Grumman	OV-1 Mohawk	Reconnaissance	Sub	Army/ MC	04-59
C-1		Grumman	TF-1 Trader	Transport (Military)	Sub	Navy	01-55
C-2		Grumman	Greyhound	Transport (Military)	Sub	Navy	11-64
E-1		Grumman	WF Tracer	Miscellaneous	Sub	Navy	12-56
E-2	A	Grumman	W2F Hawkeye	Miscellaneous	Sub	Navy	04-61
E-2	B	Grumman	W2F Hawkeye	Miscellaneous	Sub	Navy	02-69
E-2	C	Grumman	W2F Hawkeye	Miscellaneous	Sub	Navy	09-72
E-2		Grumman	W2F Hawkeye	Miscellaneous	Sub	Navy	10-60
E-8		Grumman	J-Stars	Miscellaneous	Sub	AF	12-88
F-11	1F	Grumman	(F9F-9) Tiger	Fighter	Super	Navy	05-56
F-11	A	Grumman	(F11F-1) Tiger	Fighter	Super	Navy	07-54
F-14	A	Grumman	Tomcat	Fighter	Super	Navy	12-70
F-14	A (plus)	Grumman	Tomcat	Fighter	Super	Navy	12-86
F-14	B	Grumman	Tomcat	Fighter	Super	Navy	09-73
F-14	D	Grumman	Tomcat	Fighter	Super	Navy	11-87
XF-9	2	Grumman	Panther	Fighter	Sub	Navy	11-47

Aircraft	Suffix	Design		TD/Prototype		FSD		Upgrade		X-Plane	
		Start	End	Start	End	Start	End	Start	End	Start	End
XB-42		04-43	06-43	07-43	08-48						
XB-43		09-43	12-43	01-44	02-47						
A-6	A	02-57	02-59			03-59	12-62				
EA-6	A	12-60	02-62			03-62	12-65				
EA-6	B	01-63	07-66					08-66	12-69		
A-6	C							09-66	12-68		
A-6	E							06-66	11-70		
AO-1		04-56	12-56			01-57	02-60				
C-1						06-53	10-55				
C-2		05-61	04-62			05-62	05-65				
E-1		06-51	12-52			11-55	02-58				
E-2	A					11-61	12-62				
E-2	B							02-69	12-71		
E-2	C							10-70	04-73		
E-2		12-55	11-57	12-57	10-60						
E-8						09-85	01-91				
F-11	1F	10-53	08-55	09-55	04-58						
F-11	A	12-52	03-53			04-53	04-56				
F-14	A	09-66	01-69			02-69	05-72				
F-14	A (plus)							07-84	11-87		
F-14	B			02-70	09-73						
F-14	D							07-84	06-90		
XF-9	2	09-45	03-46	04-46	11-47						

Aircraft	Suffix	Firm	Name	Type	Sonic	Service	1st Flight
F-9	2,3,5	Grumman	Panther	Fighter	Sub	NV/ MC	11-50
F-9	6,7	Grumman	Cougar	Fighter	Sub	NV/ MC	09-51
F-9	8	Grumman	Cougar	Fighter	Sub	NV/ MC	01-54
F-9	8T	Grumman	Cougar	Trainer	Sub	NV/ MC	02-56
HU-16	(UF-1G)	Grumman	UF-1G Albatross	Miscellaneous	Sub	CG	05-51
HU-16	A	Grumman	SA-16 Albatross	Miscellaneous	Sub	AF	10-47
HU-16	B	Grumman	SA-16 Albatross	Miscellaneous	Sub	AF	01-56
HU-16	C	Grumman	UF-1 Albatross	Miscellaneous	Sub	Navy	12-49
S-2	A	Grumman	Tracker	Miscellaneous	Sub	Navy	12-52
S-2	D	Grumman	Tracker	Miscellaneous	Sub	Navy	05-59
X-29	A	Grumman		Fighter	Super	AF/ DARPA	12-84
XF10F	1	Grumman	Jaguar	Fighter	Sub	Navy	05-52
EF-111	A	Grumman/ Convair GD	Raven	Reconnaissance	Super	AF	12-75
F-111	B	Grumman/ Convair GD		Fighter	Super	Navy	05-65
A-12		Lockheed	Blackbird	Fighter	Super	CIA	04-62
C-130	A	Lockheed	Hercules	Transport (Military)	Sub	AF	08-54
C-130	B	Lockheed	Hercules	Transport (Military)	Sub	AF	11-58
C-130	E	Lockheed	Hercules	Transport (Military)	Sub	AF	08-61
C-130	H	Lockheed	Hercules	Transport (Military)	Sub	AF	11-64
C-130	J	Lockheed	Hercules	Transport (Military)	Sub	AF	04-96
C-140		Lockheed		Transport (Military)	Sub	AF	09-57
C-141		Lockheed	Starlifter	Transport (Military)	Sub	AF	12-63
C-5	A	Lockheed	Galaxy	Transport (Military)	Sub	AF	06-68

Aircraft	Suffix	Design		TD/Prototype		FSD		Upgrade		X-Plane	
		Start	End	Start	End	Start	End	Start	End	Start	End
F-9	2,3,5					12-47	11-50				
F-9	6,7					03-51	11-52				
F-9	8							04-53	04-54		
F-9	8T							11-53	07-56		
HU-16	(UF-1G)							04-50	05-51		
HU-16	A					11-44	12-49				
HU-16	B							04-55	01-56		
HU-16	C							11-44	12-49		
S-2	A	01-50	09-50			10-50	02-53				
S-2	D	10-57	11-57					12-57	05-59		
X-29	A	01-76	11-81							12-81	04-85
XF10F	1	11-46	03-48	04-48	04-53						
EF-111	A					01-75	09-77				
F-111	B					11-62	05-68				
A-12		09-57	10-58			11-58	11-65				
C-130	A	01-51	06-51			07-51	12-55				
C-130	B							12-58	06-59		
C-130	E							01-61	12-61		
C-130	H							06-62	01-64		
C-130	J							03-94	12-96		
C-140						01-56	05-60				
C-141		04-60	03-61			04-61	10-64				
C-5	A	03-64	09-65			10-65	10-69				

Aircraft	Suffix	Firm	Name	Type	Sonic	Service	1st Flight
C-5	B	Lockheed	Galaxy	Transport (Military)	Sub	AF	09-85
D-21		Lockheed		Unmanned vehicle	Super	CIA	07-66
ELECTRA		Lockheed		Transport (Civilian)	Sub	—	12-57
F-104	A	Lockheed	Starfighter	Fighter	Super	AF	02-56
F-104	B	Lockheed	Starfighter	Fighter	Super	AF	01-57
F-104	C	Lockheed	Starfighter	Fighter	Super	AF	07-58
F-104	D	Lockheed	Starfighter	Fighter	Super	AF	10-58
F-104	G	Lockheed	Starfighter	Fighter	Super	AF	10-62
XF-104		Lockheed		Fighter	Super	AF	02-54
F-117	A	Lockheed	Nighthawk	Fighter	Sub	AF	06-82
F-117		Lockheed	Nighthawk	Fighter	Sub	AF	06-81
F-80	A/C	Lockheed	Shooting Star	Fighter	Sub	AF	01-44
F-94	A	Lockheed	Starfire	Fighter	Sub	AF	07-49
F-94	B	Lockheed	Starfire	Fighter	Sub	AF	12-50
F-94	C	Lockheed	(YF-97A)	Fighter	Sub	AF	01-50
L-1011		Lockheed		Transport (Civilian)	Sub	—	11-70
P-3	A	Lockheed	Orion	Miscellaneous	Sub	Navy	11-59
P-3	C	Lockheed	Orion	Miscellaneous	Sub	Navy	09-68
P2V	1	Lockheed	Neptune	Miscellaneous	Sub	Navy	05-45
S-3	A	Lockheed	Viking	Miscellaneous	Sub	Navy	11-73
S-3		Lockheed	Viking	Miscellaneous	Sub	Navy	01-72
SR-71		Lockheed	Blackbird	Fighter	Super	AF	12-64
TR-1	A	Lockheed	(U-2R)	Reconnaissance	Sub	AF	08-81

Aircraft	Suffix	Design		TD/Prototype		FSD		Upgrade		X-Plane	
		Start	End	Start	End	Start	End	Start	End	Start	End
C-5	B					07-82	01-86				
D-21						06-63	07-66				
ELECTRA		01-54	05-55			06-55	08-58				
F-104	A					07-54	01-58				
F-104	B							12-55	12-57		
F-104	C	07-58	09-58					07-58	10-58		
F-104	D							10-58	11-58		
F-104	G							12-60	10-62		
XF-104		07-49	12-52	01-53	07-54						
F-117	A					05-82	10-83				
F-117				11-78	04-82						
F-80	A/C					06-43	10-44				
F-94	A					10-48	05-50				
F-94	B							12-50	04-51		
F-94	C	01-49	12-49					01-50	03-53		
L-1011		03-66	02-68			03-68	11-70				
P-3	A	08-57	03-58			04-58	03-62				
P-3	C							09-68	06-69		
P2V	1	12-41	03-44			04-44	03-47				
S-3	A					05-72	12-73				
S-3		12-65	07-69			08-69	04-72				
SR-71						02-63	01-66				
TR-1	A					01-80	09-81				

Aircraft	Suffix	Firm	Name	Type	Sonic	Service	1st Flight
TR-1	B	Lockheed	U-2R, Trainer	Reconnaissance	Sub	AF	08-81
U-2		Lockheed		Reconnaissance	Sub	CIA	08-55
X-7	A	Lockheed		Unmanned vehicle	Sub	AF	04-51
X-7	A-3	Lockheed		Unmanned vehicle	Sub	AF	05-55
XF-90		Lockheed		Fighter	Sub	AF	06-49
XFV-1		Lockheed	Salmon	Miscellaneous	Sub	AF	06-54
XST	HAVE BLUE	Lockheed	Have Blue	Fighter	Sub	AF	12-77
YF-12	A	Lockheed	Blackbird	Fighter	Super	AF	08-63
F-22	A/B	Lockheed/ Boeing/GD		Fighter	Super	AF	06-96
YF-22		Lockheed/ Boeing/GD		Fighter	Super	AF	09-90
B-57	A	Martin	Intruder	Bomber	Sub	AF	07-53
RB-57	A	Martin	Intruder	Reconnaissance	Sub	AF	10-53
B-57	B	Martin	Intruder	Bomber	Sub	AF	06-54
RB-57	B	Martin	Intruder	Bomber	Sub	AF	11-55
B-57	C	Martin	Intruder	Bomber	Sub	AF	12-54
RB-57	D/F	Martin	Intruder	Reconnaissance	Sub	AF	
B-57	E	Martin	Intruder	Bomber	Sub	AF	05-56
TM-61	A/C	Martin	Matador	Unmanned vehicle	Sub	AF	12-52
TM-61		Martin	Matador (B-61)	Unmanned vehicle	Sub	AF	01-49
TM-76	A/B	Martin	Mace (TM-61b)	Unmanned vehicle	Sub	AF	06-58
X-23	A	Martin	Prime	Unmanned vehicle	Super	AF	12-66
XB-48		Martin		Bomber	Sub	AF	06-47
XB-51		Martin		Bomber	Sub	AF	10-49

Aircraft	Suffix	Design		TD/Prototype		FSD		Upgrade		X-Plane	
		Start	End	Start	End	Start	End	Start	End	Start	End
TR-1	B					01-80	01-83				
U-2		03-53	12-54			01-55	06-56				
X-7	A									12-46	12-53
X-7	A-3									01-54	07-60
XF-90				06-46	06-49						
XFV-1		01-50	03-51	04-51	06-55						
XST	HAVE BLUE	10-74	03-76	04-76	07-79						
YF-12	A			06-60	03-64						
F-22	A/B					08-91	12-96				
YF-22		12-83	10-86	11-86	07-91						
B-57	A	09-50	02-51			03-51	07-53				
RB-57	A							10-51	07-54		
B-57	B							08-52	10-54		
RB-57	B	04-53	05-54					06-54	05-56		
B-57	C	02-53	03-54					04-54	01-55		
RB-57	D/F	07-53	12-53					01-54	03-56		
B-57	E	03-54	01-55					02-55	08-56		
TM-61	A/C					09-50	06-52				
TM-61		08-45	05-47	06-47	09-50						
TM-76	A/B					10-54	11-60				
X-23	A									08-64	04-67
XB-48		11-44	11-46	12-46	06-47						
XB-51		01-46	04-46	05-46	11-51						

Aircraft	Suffix	Firm	Name	Type	Sonic	Service	1st Flight
XB-68		Martin		Bomber	Super	AF	
BGM-109	Block 3	McDonnell	TWS (Tomahawk)	Unmanned vehicle	Sub	Navy	02-91
DC-10		McDonnell		Transport (Civilian)	Sub	—	08-70
KC-10		McDonnell		Transport (Military)	Sub	—	07-80
C-17	A	McDonnell	Globemaster III	Transport (Military)	Sub	AF	09-91
F-101	A	McDonnell	Voodoo	Fighter	Super	AF	09-54
RF-101	A	McDonnell	Voodoo	Reconnaissance	Sub	AF	06-55
F-101	B	McDonnell	Voodoo	Fighter	Super	AF	03-57
F-15	A	McDonnell	Eagle	Fighter	Super	AF	07-72
F-15	B	McDonnell	Eagle	Fighter	Super	AF	07-73
F-15	C	McDonnell	Eagle	Fighter	Super	AF	02-79
F-15	D	McDonnell	Eagle	Fighter	Super	AF	06-79
F-15	E	McDonnell	Strike Eagle	Bomber	Super	AF	12-86
F-15	S/MTD	McDonnell	(NF-15-B)	Fighter	Super	AF	09-88
F-2	A	McDonnell	F2H-1 Banshee	Fighter	Sub	Navy	01-47
F-2	B	McDonnell	F2H-2 Banshee	Fighter	Sub	Navy	08-49
F-2	C	McDonnell	F2H-3 Banshee	Fighter	Sub	Navy	03-52
XF-2		McDonnell	Banshee	Fighter	Sub	Navy	01-47
F-3	B	McDonnell	F3H-2, Demon	Fighter	Sub	Navy	06-55
MF-3	B	McDonnell	F3H-2M, Demon	Fighter	Sub	Navy	08-55
F-3	C	McDonnell	F3H-2N, Demon	Fighter	Sub	Navy	04-54
XF-3		McDonnell	XF3H-1, Demon	Fighter	Sub	Navy	08-51
F-3		McDonnell	F3H-1N, Demon	Fighter	Sub	Navy	12-53

Aircraft	Suffix	Design		TD/Prototype		FSD		Upgrade		X-Plane	
		Start	End	Start	End	Start	End	Start	End	Start	End
XB-68		09-56	04-57								
BGM-109	Block 3							12-88	02-92		
DC-10		07-67	01-68			02-68	07-71				
KC-10						12-77	03-81				
C-17	A	02-80	09-81			12-85	05-93				
F-101	A	02-51	12-51			01-52	08-54				
RF-101	A							09-54	06-55		
F-101	B	04-54	02-55					03-55	01-59		
F-15	A	04-66	11-69			12-69	11-74				
F-15	B							01-73	11-74		
F-15	C							07-78	07-79		
F-15	D							07-78	07-79		
F-15	E					02-84	12-88				
F-15	S/MTD			10-84	08-91						
F-2	A					05-47	08-48				
F-2	B							05-48	08-49		
F-2	C							07-50	03-52		
XF-2				03-45	01-47						
F-3	B							06-55	06-56		
MF-3	B							05-54	09-55		
F-3	C							08-53	09-55		
XF-3		05-48	08-49	09-49	02-51						
F-3						03-51	02-55				

Aircraft	Suffix	Firm	Name	Type	Sonic	Service	1st Flight
F-4	A	McDonnell	Phantom II	Fighter	Super	Navy	05-58
F-4	B	McDonnell	Phantom II	Fighter	Super	Navy	02-60
F-4	C	McDonnell	F-110A Phantom	Fighter	Super	AF	05-63
RF-4	C	McDonnell	Phantom II	Reconnaissance	Super	AF	08-63
F-4	D	McDonnell	Phantom II	Fighter	Super	AF	06-65
F-4	E	McDonnell	Phantom II	Fighter	Super	AF	06-67
F/A-18	C/D	McDonnell	Hornet	Fighter	Super	Navy	05-88
F/A-18	D RC	McDonnell	Hornet	Reconnaissance	Super	Navy	06-84
F/A-18	E/F	McDonnell	Super Hornet	Fighter	Super	Navy	11-95
MD-11		McDonnell		Transport (Civilian)	Sub	—	01-90
MD-80		McDonnell		Transport (Civilian)	Sub	—	10-79
MD-90		McDonnell		Transport (Civilian)	Sub	—	02-93
T-45	A	McDonnell	Goshawk	Trainer	Super	Navy	04-88
XF-85		McDonnell	Goblin	Fighter	Sub	AF	08-48
XF-88		McDonnell	Voodoo	Fighter	Sub	AF	10-48
YC-15		McDonnell		Transport (Military)	Sub	AF	08-75
AV-8B		McDonnell/ BAE	Harrier II	Fighter	Sub	Marine Corps	11-78
A-12		McDonnell/ Convair GD	Avenger	Bomber	Sub	Navy	
F/A-18	A/B	McDonnell/ Northrop	Hornet	Fighter	Super	Navy	11-78
A-2	A/B	NAA	Savage (AJ-1/2)	Fighter	Sub	Navy	07-48
A-5	A	NAA	(A3J) Vigilante	Fighter	Super	Navy	08-58
A-5	B	NAA	Vigilante	Fighter	Super	Navy	04-62
RA-5	C	NAA	Vigilante	Reconnaissance	Super	Navy	06-62

Aircraft	Suffix	Design		TD/Prototype		FSD		Upgrade		X-Plane	
		Start	End	Start	End	Start	End	Start	End	Start	End
F-4	A	08-53	09-54			10-54	11-58				
F-4	B							12-58	02-60		
F-4	C							03-62	11-63		
RF-4	C							05-62	09-64		
F-4	D							03-64	04-66		
F-4	E							07-66	10-67		
F/A-18	C/D							10-85	11-89		
F/A-18	D RC					06-82	06-84				
F/A-18	E/F	09-91	11-92			12-92	12-96				
MD-11						12-86	11-90				
MD-80						10-77	08-80				
MD-90						11-89	11-94				
T-45	A	03-80	09-84			10-84	08-89				
XF-85		09-44	09-45	10-45	09-49						
XF-88		01-46	01-47	02-47	12-48						
YC-15		01-72	10-72	11-72	08-79						
AV-8B		05-75	06-76			07-76	06-82				
A-12		11-84	12-87			01-88	01-91				
F/A-18	A/B	05-72	12-75			01-76	05-80				
A-2	A/B					06-46	09-49				
A-5	A					07-55	02-60				
A-5	B							07-56	12-63		
RA-5	C							07-56	12-63		

Aircraft	Suffix	Firm	Name	Type	Sonic	Service	1st Flight
B-45	A	NAA	Tornado	Bomber	Sub	AF	03-47
B-45	C	NAA	Tornado	Bomber	Sub	AF	05-49
RB-45	C	NAA	Tornado	Reconnaissance	Sub	AF	04-50
F-1	FJ-1	NAA	Fury	Fighter	Sub	Navy	09-46
F-1	FJ-2	NAA	Fury	Fighter	Sub	Navy	12-51
F-1	FJ-3	NAA	Fury	Fighter	Sub	Navy	03-53
F-1	FJ-4	NAA	Fury	Fighter	Sub	Navy	10-54
F-100	A	NAA	Super Sabre	Fighter	Super	AF	05-53
F-100	C	NAA	Super Sabre	Fighter	Super	AF	03-54
F-100	D	NAA	Super Sabre	Fighter	Super	AF	01-56
F-100	F	NAA	Super Sabre	Fighter	Super	AF	08-56
F-86	(XP-86)	NAA	Sabre	Fighter	Sub	AF	10-47
F-86	A	NAA	Sabre	Fighter	Sub	AF	10-47
F-86	D	NAA	YF-95A. Sabre Dog	Fighter	Sub	AF	09-49
F-86	E	NAA	Sabre	Fighter	Sub	AF	05-50
F-86	F	NAA	Sabre	Fighter	Sub	AF	03-52
F-86	H	NAA	Sabre	Fighter	Sub	AF	05-53
F-86	K	NAA		Fighter	Sub	AF	07-54
F-86	L	NAA		Fighter	Sub	AF	10-56
T-2		NAA	Buckeye	Trainer	Sub	Navy	02-58
T-28		NAA	Trojan	Trainer	Sub	Navy	09-49
X-10	XSM-64	NAA	Navaho	Unmanned vehicle	Super	AF	03-57
X-15		NAA		Fighter	Super	AF/NV/ NASA	09-59

Aircraft	Suffix	Design		TD/Prototype		FSD		Upgrade		X-Plane	
		Start	End	Start	End	Start	End	Start	End	Start	End
B-45	A	01-44	08-44			09-44	03-48				
B-45	C							09-47	05-49		
RB-45	C							01-49	06-50		
F-1	FJ-1					01-45	03-48				
F-1	FJ-2					03-51	12-52				
F-1	FJ-3							03-52	12-52		
F-1	FJ-4							01-53	02-55		
F-100	A	09-50	12-50			01-51	09-54				
F-100	C							02-54	07-55		
F-100	D							05-54	06-56		
F-100	F							09-55	01-58		
F-86	(XP-86)	01-45	12-46	01-47	10-47						
F-86	A					01-47	02-49				
F-86	D					03-49	04-53				
F-86	E							09-49	05-50		
F-86	F							01-51	03-52		
F-86	H							03-51	09-54		
F-86	K							03-53	06-55		
F-86	L							01-55	10-56		
T-2						07-56	02-58				
T-28						07-48	09-49				
X-10	XSM-64	04-46	02-47							03-47	03-60
X-15		12-54	05-56							06-56	12-61

Aircraft	Suffix	Firm	Name	Type	Sonic	Service	1st Flight
XB-70	A	NAA	Valkyrie	Bomber	Super	AF	09-64
XF-108		NAA	Rapier	Fighter	Super	Navy	
YF-107	A	NAA		Fighter	Sub	AF	09-56
YF-93	A	NAA	(F-86C) Sabre	Fighter	Sub	AF	01-50
B-1	A	NAA/ Rockwell		Bomber	Super	AF	12-74
B-1	B	NAA/ Rockwell	Lancer	Bomber	Sub	AF	10-84
HiMat		NAA/ Rockwell		Unmanned vehicle	Super	AF	
X-31	A EFM	NAA/Rock-well/Dasa		Fighter	Super	NASA	10-90
AGM-137		Northrop	TSSAM	Unmanned vehicle	Sub	AF	06-90
B-2	A	Northrop	Spirit	Bomber	Sub	AF	07-89
YRB-49	A	Northrop		Reconnaissance	Sub	AF	05-50
YB-49		Northrop		Bomber	Sub	AF	10-47
F-20	(F-5G)	Northrop	F-20 Tigershark	Fighter	Super	AF	08-82
F-5	A	Northrop	Freedom Fighter	Fighter	Super	AF	05-63
RF-5	A	Northrop	Freedom Fighter	Reconnaissance	Super	AF	05-68
F-5	B	Northrop	Freedom Fighter	Fighter	Super	AF	02-64
F-5	E	Northrop	Freedom Fighter	Fighter	Super	AF	08-72
F-5	F	Northrop	Freedom Fighter	Trainer	Super	AF	09-74
F-5	N-156	Northrop	Freedom Fighter	Fighter	Super	AF	07-59
F-89	A	Northrop	Scorpion	Fighter	Sub	AF	08-48
F-89	B	Northrop	Scorpion	Fighter	Sub	AF	02-51
F-89	C	Northrop	Scorpion	Fighter	Sub	AF	09-51
F-89	D	Northrop	Scorpion	Fighter	Sub	AF	01-54

Aircraft	Suffix	Design		TD/Prototype		FSD		Upgrade		X-Plane	
		Start	End	Start	End	Start	End	Start	End	Start	End
XB-70	A	01-54	09-54	10-54	12-64						
XF-108				10-55	09-59						
YF-107	A	07-53	12-54	01-55	03-57						
YF-93	A			06-46	01-50						
B-1	A	11-63	05-70			06-70	12-81				
B-1	B					01-82	07-85				
HiMat						06-79	01-83				
X-31	A EFM	11-84	09-86							08-88	04-94
AGM-137				06-86	12-94						
B-2	A	10-81	10-87			11-87	12-93				
YRB-49	A			03-48	09-50						
YB-49				06-45	03-50						
F-20	(F-5G)			03-80	10-86						
F-5	A					10-62	01-64				
RF-5	A							10-63	06-68		
F-5	B							10-62	03-64		
F-5	E	01-69	11-70			12-70	04-73				
F-5	F							01-74	09-74		
F-5	N-156	01-55	12-56	07-59	04-62						
F-89	A	08-45	05-46			06-46	09-50				
F-89	B							10-50	02-51		
F-89	C							03-51	09-51		
F-89	D							06-52	11-53		

Aircraft	Suffix	Firm	Name	Type	Sonic	Service	1st Flight
F-89	H	Northrop	Scorpion	Fighter	Sub	AF	09-55
F-89	J	Northrop	Scorpion	Fighter	Sub	AF	11-56
SM-62	A-D	Northrop	Snark (N-69A-D)	Unmanned vehicle	Sub	AF	06-54
SM-62	E	Northrop	Snark (N-69E)	Unmanned vehicle	Sub	AF	08-57
SM-62		Northrop	Snark (N-25)	Unmanned vehicle	Sub	AF	04-51
T-38		Northrop	Talon	Trainer	Super	AF	04-59
X-21	A	Northrop		Bomber	Sub	AF	04-63
X-4		Northrop	Skylancer (Bantam)	Fighter	Sub	AF/ NACA	12-48
XB/YB-35		Northrop		Bomber	Sub	AF	06-46
XST		Northrop		Fighter	Sub	AF	
YA-9	A	Northrop		Fighter	Sub	AF	05-72
YF-17		Northrop		Fighter	Super	AF	06-74
YF-23		Northrop/ McDonnell		Fighter	Super	AF	08-90
F-105	A	Republic	Thunderchief	Fighter	Super	AF	10-55
F-105	B	Republic	Thunderchief	Fighter	Super	AF	05-56
F-105	D	Republic	Thunderchief	Fighter	Super	AF	06-59
F-105	F	Republic	Thunderchief	Fighter	Super	AF	06-63
EF-105	F	Republic	Thunderchief	Reconnaissance	Super	AF	05-66
F-84	(XP-84)	Republic	Thunderjet	Fighter	Sub	AF	02-46
F-84	B-C	Republic	Thunderjet	Fighter	Sub	AF	06-47
F-84	D	Republic	Thunderjet	Fighter	Sub	AF	11-47
F-84	F, (YF-96A)	Republic	Thunderstreak	Fighter	Sub	AF	06-50
XF-103		Republic		Fighter	Super	AF	

Aircraft	Suffix	Design		TD/Prototype		FSD		Upgrade		X-Plane	
		Start	End	Start	End	Start	End	Start	End	Start	End
F-89	H							01-54	09-55		
F-89	J							10-55	11-56		
SM-62	A-D			06-50	05-57						
SM-62	E			06-57	05-59						
SM-62				03-46	03-52						
T-38		01-55	04-56			05-56	03-61				
X-21	A									08-60	04-63
X-4										06-46	05-50
XB/YB-35		05-41	08-41	09-41	11-49						
XST		04-75	04-76								
YA-9	A	03-67	11-70	12-70	12-72						
YF-17		01-72	03-72	04-72	12-74						
YF-23		12-83	10-86	11-86	04-91						
F-105	A	07-51	05-52			06-52	01-56				
F-105	B							06-52	04-58		
F-105	D							06-57	12-59		
F-105	F							05-62	12-63		
EF-105	F							07-65	05-66		
F-84	(XP-84)			09-44	01-47						
F-84	B-C					02-47	06-47				
F-84	D							07-47	11-47		
F-84	F, (YF-96A)			11-49	02-51						
XF-103		04-48	08-51	09-51	09-57						

Aircraft	Suffix	Firm	Name	Type	Sonic	Service	1st Flight
XF-91		Republic	Thunderceptor	Fighter	Sub	AF	05-49
A-10	A	Republic/ Fairchild	Thunderbolt II	Fighter	Sub	AF	10-75
A-10	B	Republic/ Fairchild	Thunderbolt II	Fighter	Sub	AF	05-79
YA-10		Republic/ Fairchild	Thunderbolt II	Fighter	Sub	AF	05-72
T-46	A	Republic/ Fairchild		Trainer	Super	AF	10-85
X-13		Ryan	Vertijet	Miscellaneous	Sub	AF	12-55
XFR1		Ryan		Fighter	Sub	AF	06-44
TA-7	C	Vought (LTV)	Corsair II	Trainer	Super	Navy	12-76
A-7	D	Vought (LTV)	Corsair II	Fighter	Super	AF	04-68
A-7	E	Vought (LTV)	Corsair II	Fighter	Super	Navy	11-68
BGM-110		Vought (LTV)		Unmanned vehicle	Sub	Navy	03-76
F-6U		Vought (LTV)	Pirate	Fighter	Sub	Navy	10-46
F-7U		Vought (LTV)	Cutlass	Fighter	Sub	Navy	09-48
F-8	A	Vought (LTV)	F8U Crusader	Fighter	Super	Navy	03-55
F-8	C	Vought (LTV)	F8U-2 Crusader	Fighter	Super	Navy	12-58
F-8	D	Vought (LTV)	F8U-2N Crusader	Fighter	Super	Navy	02-60
F-8	E	Vought (LTV)	F8U-2NE Crusader	Fighter	Super	Navy	06-61
SSM	8-A	Vought (LTV)	Regulus I	Unmanned vehicle	Sub	Navy	03-51
SSM	9	Vought (LTV)	Regulus II	Unmanned vehicle	Super	Navy	11-57

Aircraft	Suffix	Design		TD/Prototype		FSD		Upgrade		X-Plane	
		Start	End	Start	End	Start	End	Start	End	Start	End
XF-91				03-46	10-51						
A-10	A					01-73	11-75				
A-10	B							04-78	12-81		
YA-10		03-67	11-70	12-70	12-72						
T-46	A					07-82	03-86				
X-13										07-54	09-58
XFR1						02-43	03-45				
TA-7	C							12-76	06-78		
A-7	D							04-68	12-68		
A-7	E							12-67	07-69		
BGM-110				12-73	02-76						
F-6U		09-44	11-44			12-44	08-49				
F-7U						06-46	12-51				
F-8	A	07-52	04-53			05-53	12-56				
F-8	C							01-57	12-58		
F-8	D							02-60	06-60		
F-8	E							06-61	10-61		
SSM	8-A					08-47	06-55				
SSM	9	04-52	05-56			06-56	12-58				

BIBLIOGRAPHY

Anderson, Fred, *Northrop: An Aeronautical History,* Hawthorne, Calif.: Northrop Corporation, 1976.

Anderton, David A., *Republic F-105 Thunderchief,* London: Osprey Publishing Ltd., 1983.

_____, *North American Super Sabre,* London: Osprey Publishing Ltd., 1987.

Armitage, Michael, *Unmanned Aircraft,* London: Brassey's Defense Publishers, 1988.

Aronstein, David C., and Albert C. Piccirillo, *Have Blue and the F-117A: Evolution of the "Stealth Fighter,"* Reston, Va.: American Institute of Aeronautics and Astronautics, 1997.

Art, Robert J., *The TFX Decision: McNamara and the Military,* Boston, Mass.: Little Brown & Company, 1968.

Baker, David, "Wizard Wars & Air Power in the 21st Century," *Air International,* September 1994a.

_____, "From ATF to Lightning II: A Bolt in Anger," *Air International,* December 1994b.

Bahret, William F., "The Beginnings of Stealth Technology," *IEEE Transactions on Aerospace and Electronic Systems,* October 1993.

Bavousett, Glenn B., *Combat Aircraft of World War II,* New York: Bonanza, 1989.

Biddle, Wayne, *Barons of the Sky,* New York: Simon & Schuster, 1991.

Biery, Frederick, *International Collaboration in the Commercial Aircraft Industry,* Santa Monica, Calif.: RAND, unpublished manuscript, October 1978.

_____, *Why Do We Buy the Weapons We Do? A Review of One Explanation,* Santa Monica, Calif.: RAND, unpublished manuscript, April 1980.

Boatman, John, "USA Planned Stealthy UAV to Replace SR-71," *Jane's Defense Weekly*, December 17, 1994.

Bodilly, Susan J., *Case Study of Risk Management in the USAF B-1B Bomber Program*, Santa Monica, Calif.: RAND, N-3616-AF, 1993.

Bowers, Peter M., *Boeing Aircraft Since 1916*, Annapolis, Md.: Naval Institute Press, 1989.

Braybrook, Roy, "F-14 and F-15: The New Wave of Warplanes," *Air Enthusiast*, March 1972.

Bright, Charles D., *The Jet Makers: The Aerospace Industry from 1945–1972*, Kan.: The Regents Press of Kansas, 1978.

Bugos, Glenn E., *F-4: Engineering the Phantom II, Parts into Systems*, Annapolis, Md.: Naval Institute Press, 1996.

_____, *Testing The F-4 Phantom II: Engineering Practice in the Development of American Military Aircraft*, 1954-1969, Ph.D. dissertation, University of Pennsylvania, 1988.

Burton, James, *The Pentagon Wars: Reformers Challenge the Old Guard*, Annapolis, Md.: Naval Institute Press, 1993.

Coulam, Robert F., *Illusions of Choice: The F-111 and the Problems of Weapons Acquisition Reform*, New York: Princeton University Press, 1977.

Delusach, Al, "Long Preparation Paid Off for McDonnell on the F-15," *St. Louis Post-Dispatch*, January 11–12, 1970.

Dorr, Robert F., *Lockheed F-117 Nighthawk*, London: Aerospace Publishing Ltd., 1995.

Drezner, Jeffrey A., Giles K. Smith, Lucille E. Horgan, Curt Rogers, and Rachel Schmidt, *Maintaining Future Military Aircraft Capability*, Santa Monica, Calif.: RAND, R-4199-AF, 1992.

Ethell, Jeff, *F-15 Eagle*, London: Ian Allan Ltd., 1981.

Ford, Daniel, "The Worst Fighter of World War II? The Sorry Saga of the Brewster Buffalo," *Air & Space Smithsonian*, June/July 1996.

Francillon, René, *McDonnell Douglas F-15A/B*, Arlington, Tex.: Aerofax, Inc., 1984.

_____, *McDonnell Douglas Aircraft Since 1920: Volume I*, 2nd ed., revised and updated, Annapolis, Md.: Naval Institute Press, 1990a.

_____, *McDonnell Douglas Aircraft Since 1920: Volume II*, 2nd ed., revised and updated, Annapolis, Md.: Naval Institute Press, 1990b.

Gallois, Pierre, "The British White Paper and the Arms Industry," *Interavia*, May 1957, pp. 453–456.

Gentry, Jerauld R., *Evolution of the F-16 Multinational Fighter*, Student Research Report, Industrial College of the Armed Forces, 1976.

Gething, Michael J., *Modern Fighting Aircraft: F-15*, New York: Arco Publishing, 1983.

Godfrey, David W. H., "B-1 Design Has Forward Fins," *Aviation Week & Space Technology*," May 4, 1970.

_____, "B-1 Airborne Strategic Deterrent," *Air International*, February 1975.

_____, "Dogfighter Supreme: The Tomcat," *Air Enthusiast International*, January 1977a.

_____, "Hawkeye: A New Dimension in Tactical Warfare," *Air Enthusiast International*, January 1977b.

Goodwin, Jacob, *Brotherhood of Arms: General Dynamics and the Business of Defending America*, New York: Times Books, 1985.

Green, William, and Gordon Swanborough, *The Complete Book of Fighters*, New York: Smithmark, 1994.

Guenther, Ben, and Jay Miller, *Bell X-1 Variants*, Arlington, Tex.: Aerofax, 1988.

Gunston, Bill, *Attack Aircraft of the West*, New York: Charles Scribner's Sons, 1974.

_____, *The Encyclopedia of the World's Combat Aircraft*, New York: Chartwell, 1978.

_____, *The Encyclopedia of World Air Power*, New York: Crescent Books, 1980.

_____, *F-111*, New York: Arco Publishing, Inc., 1983.

_____, *Modern Airborne Missiles*, London: Arco Publishing, Inc., 1983.

_____, *Modern Fighting Aircraft*, New York: The Military Press, 1984.

_____, *F/A-18 Hornet*, London: Ian Allen Ltd., 1985.

_____, *Jet Bombers from the Messerschmitt Me 262 to the Stealth B-2*, London: Osprey Publishing Ltd., 1993.

Hall, G. R., and R. E. Johnson, *Transfers of United States Aerospace Technology to Japan*, Santa Monica, Calif.: RAND, P-3875, 1968.

Hallion, Richard P., *The Evolution of Commonality in Fighter and Attack Aircraft Development and Usage*, Edwards Air Force Base, Calif.: History Office, U.S. Air Force Flight Test Center, November 1985.

_____, "A Troubling Past: Air Force Fighter Acquisition Since 1945," *Air Power Journal*, Vol. IV, No. 4, Winter 1990, pp. 4–23.

Head, Richard G., "Doctrinal Innovation and the A-7 Attack Aircraft Decisions," in Richard G. Head and Ervin J. Rokke, eds., *American Defense Policy*, Third Edition, Baltimore: The Johns Hopkins University Press, 1975.

Holder, William G., *Boeing B-52 Stratofortress*, Fallbrook, Calif.: Aero Publishers, Inc., 1975.

Ingells, Douglas, *L-1011 TriStar and the Lockheed Story*, Fallbrook, Calif.: Aero Publishers, Inc., 1973.

Johnson, Clarence L., and Maggie Smith, *Kelly: More Than My Share of It All*, Washington, D.C.: Smithsonian Institution Press, 1985.

Johnson, L. L., *The Century Series Fighters: A Study in Research and Development*, Santa Monica, Calif.: RAND, RM-2549, 1960.

Jones, Lloyd S., *U.S. Naval Fighters*, Fallbrook, Calif.: Aero Publishers, Inc., 1977.

_____, *U.S. Bombers: 1928 to 1980s*, Fallbrook, Calif.: Aero Publishers, Inc., 1980.

Kennedy, Dee, et al., "Dawn of Stealth," *Lockheed Horizons: We Own the Night*, May 1992.

Klein, Burton H., et al., *Research and Development Policies*, Santa Monica, Calif.: RAND, R-333, 1958.

Knaack, Marcelle Size, *Post–World War II Fighters: 1945–1973*, Washington, D.C.: Office of Air Force History, 1978.

_____, *Post World War II Bombers: 1945–1973*, Washington, D.C.: Office of Air Force History, 1988.

Kotz, Nick, *Wild Blue Yonder: Money, Politics and the B-1 Bomber*, New York: Pantheon Books, 1988.

Lopez, Ramon, "Out of the Black Comes Tacit Blue," *Flight International*, May 8–14, 1996.

Lorell, Mark A., *The Use of Prototypes in Selected Foreign Fighter Aircraft Development Programs*, Santa Monica, Calif.: RAND, R-3687-P&L, 1989.

_____, with Alison Sanders and Hugh Levaux, *Bomber R&D Since 1945: The Role of Experience,* Santa Monica, Calif.: RAND, MR-670-AF, 1995.

Lynch, David J., "How the Skunk Works Fielded Stealth," *Air Force Magazine,* November 1992.

Martin, Tom, and Rachel Schmidt, *A Case Study of the F-20 Tigershark,* Santa Monica, Calif.: RAND, P-7495-RGS, 1987.

Mason, Francis K., *Phantom: A Legend in Its Own Time,* Osceola, Wisc.: Motorbooks International, 1984.

Mayer, Kenneth R., *The Political Economy of Defense Contracting,* New Haven, Conn.: Yale University Press, 1991.

Mendenhall, Charles A., *Delta Wings: Convair's High-Speed Planes of the Fifties and Sixties,* Osceola, Wisc.: Motorbooks International, 1983.

Miller, Jay, *General Dynamics F-16 Fighting Falcon,* Arlington, Tex.: Aerofax, Inc., 1982.

_____, *Lockheed SR-71 (A/12YF-12/D-21),* Arlington, Tex.: Aerofax, Inc., 1983a.

_____, *The X-Planes: X-1 to X-29,* Minn.: Specialty Press, 1983b.

_____, *Convair B-58,* Arlington, Tex.: Aerofax, Inc., 1985.

Mintz, John, "Navy Defers Repayment Demand on Stealth Plane; Move Seen as Reprieve for McDonnell Douglas," *The Washington Post,* December 16, 1992.

Munson, Kenneth, *Fighters Between the Wars, 1919–39,* London: Blandford Press, 1970.

Munson, Kenneth, and Gordon Swanborough, *Boeing: An Aircraft Album No. 4,* New York: Arco Publishing, Inc., 1972.

Orr, Kelly, *Hornet: The Inside Story of the F/A-18,* Shrewsbury, England: Airlife Publishing, 1991.

Pace, Steve, *Valkyrie: North American XB-70A,* Fallbrook, Calif.: Aero Publishers, Inc., 1984.

_____, *Lockheed Skunk Works,* Osceola, Wisc.: Motorbooks International, 1992.

_____, *Edwards Air Force Base: Experimental Flight Test Center,* Osceola, Wisc.: Motorbooks International, 1994.

Perry, Robert L., *Antecedents of the X-1,* Santa Monica, Calif.: RAND, P-3154, 1965.

_____, *Variable Sweep: A Case History of Multiple Re-Innovation,* Santa Monica, Calif.: RAND, P-3459, 1966.

_____, *A Prototype Strategy for Aircraft Development*, Santa Monica, Calif.: RAND, RM-5597-1-PR, 1972.

Pint, Ellen M., and Rachel Schmidt, *Financial Condition of U.S. Military Aircraft Prime Contractors*, Santa Monica, Calif.: RAND, MR-372-AF, 1994.

Rich, Ben R. and Leo Janos, *Skunk Works: A Personal Memoir of My Years at Lockheed*, Boston, Mass.: Little Brown & Company, 1994.

Rich, Michael D., et al., *Improving the Military Acquisition Process: Lessons from RAND Research*, Santa Monica, Calif.: RAND, R-3373-AF/RC, 1986.

Scott, William B., *Inside the Stealth Bomber: The B-2 Story*, Blue Ridge Summit, Pa.: TAB/Aero Books, 1991a.

_____, "TR-3A Evolved from Classified Prototypes Based on Tactical Penetrator Concept," *Aviation Week and Space Technology*, June 10, 1991b.

_____, "Triangular Reconnaissance Aircraft May Be Supporting F-117A," *Aviation Week and Space Technology*, June 10, 1991c.

Scutts, J. C., *F-105 Thunderchief*, London: Ian Allen Ltd., 1981.

Serling, Robert J., *Legend and Legacy: The Story of Boeing and Its People*, New York: St. Martin's Press, 1992.

Shenon, Philip, "Jet Makers Preparing Bids for a Rich Pentagon Prize," *The New York Times*, March 12, 1996.

Smith, Giles K., and Ellen T. Friedmann, *An Analysis of Weapon System Acquisition Intervals, Past and Present*, Santa Monica, Calif.: RAND, R-2605-DR&E/AF, 1980.

Smith, Giles K., A. A. Barbour, T. L. McNaugher, M. D. Rich, and William L. Stanley, *The Use of Prototypes in Weapon System Development*, Santa Monica, Calif.: RAND, R-2345-AF, 1981.

Sorrels, Charles A., *U.S. Missile Programs: Development, Deployment and Implications for Arms Control*, New York: McGraw-Hill Inc., 1983.

Sponsler, George C., N. Rubin, D. Gignoux, and E. Dare, *The F-4 and the F-14*, Gaithersburg, Md.: Columbia Research Corporation, May 1973.

Stevenson, James Perry, *Grumman F-14 "Tomcat,"* Fallbrook, Calif.: Aero Publishers, Inc., 1975.

_____, *McDonnell Douglas F-15 Eagle*, Fallbrook, Calif.: Aero Publishers, Inc., 1978.

_____, *The Pentagon Paradox: The Development of the F-18 Hornet*, Annapolis, Md.: Naval Institute Press, 1993.

Stoff, Joshua, *The Thunder Factory. An Illustrated History of the Republic Aviation Corporation,* Osceola, Wisc.: Motorbooks International, 1990.

_____, *Picture History of World War II American Aircraft Production,* New York: Dover, 1993.

Stuart, William G., *Northrop Case Study in Aircraft Design,* Hawthorne, Calif.: Northrop Corporation, September 1978.

Stubbing, Richard A., *The Defense Game,* New York: Harper & Row Publishers, 1986.

Swanborough, Gordon, *United States Military Aircraft Since 1909,* London & New York: Putnam, 1963.

_____, *Military Transports and Training Aircraft of the World,* London: Temple Press Books, 1965.

_____, *United States Navy Aircraft Since 1911,* London: Putnam, 1968.

Sweetman, Bill, *A-10 Thunderbolt II,* New York: Arco Publishing, Inc., 1984.

_____, *Phantom,* London: Jane's Publishing Company Limited, 1984.

_____, *Stealth Bomber: Invisible Warplane, Black Budget,* Osceola, Wisc.: Motorbooks International, 1986.

_____, "Lockheed YF-22: Stealth with Agility," *World Airpower Journal,* Vol. 6, Summer 1991a.

_____, "The Fighter They Didn't Want," *World Airpower Journal,* Vol. 7, Autumn/Winter, 1991b.

_____, *Northrop B-2 Stealth Bomber,* Osceola, Wisc.: Motorbooks International, 1992.

_____, "Send in the Drones," *Popular Science,* October 1995.

Sweetman, Bill, and James Goodall, *Lockheed F-117A: Operation and Development of the Stealth Fighter,* Osceola, Wisc.: Motorbooks International, 1990.

Taylor, Michael J. H., *Boeing,* London: Jane's Publishing Company Limited, 1982.

Thornborough, Anthony M., and Peter E. Davies, *Grumman A-6 Intruder Prowler,* London: Ian Allen Ltd., 1987.

U.S. House of Representatives, *The Navy's A-12 Aircraft Program,* testimony before the Procurement and Nuclear Systems Subcommittee, Research and Development Subcommittee, and Investigations Subcommittee of the House Committee on the Armed Services, Washington, D.C.: U.S. Government Printing Office, 1990.

_____, *A-12 Acquisition*, testimony before the Investigation Subcommittee of the Committee on the Armed Services, Washington, D.C.: U.S. Government Printing Office, 1991.

_____, *A-12 Navy Aircraft*, testimony before the Legislation and National Security Subcommittee of the Committee on Government Operations, Washington, D.C.: U.S. Government Printing Office, 1991.

_____, Committee on Armed Services, *A-12 Acquisition*, Washington, D.C.: U.S. Government Printing Office, 1992a.

_____, Committee on Government Operations, *Oversight Hearing on the A-12 Navy Aircraft*, Washington, D.C.: U.S. Government Printing Office, 1992b.

Vartabedian, Ralph, "Pentagon Cancels Northrop Stealth Missile Program," *Los Angeles Times*, December 10, 1994, p. D1.

Wagner, William, *Lightning Bugs and Other Reconnaissance Drones*, Fallbrook, Calif.: Armed Forces Journal International and Aero Publishers, Inc., 1982.

White, William D., *U.S. Tactical Air Power: Missions, Forces, and Costs*, Washington, D.C.: The Brookings Institution, 1974.

Yenne, Bill, *Lockheed*, New York: Crescent Books, 1980.

_____, *McDonnell Douglas: A Tale of Two Giants*, New York: Crescent Books, 1985.

Yoshimura, Akira, *Zero Fighter*, Westport, Conn.: Praeger, 1996.

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